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Psychological origins of the Industrial Revolution

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Abstract

Since the Industrial Revolution, human societies have experienced high and sustained rates of economic growth. Recent explanations of this sudden and massive change in economic history have held that modern growth results from an acceleration of innovation. But it is unclear why the rate of innovation drastically accelerated in England in the eighteenth century. An important factor might be the alteration of individual preferences with regard to innovation resulting from the unprecedented living standards of the English during that period, for two reasons. First, recent developments in economic history challenge the standard Malthusian view according to which living standards were stagnant until the Industrial Revolution. Preindustrial England enjoyed a level of affluence that was unprecedented in history. Second, behavioral sciences have demonstrated that the human brain is designed to respond adaptively to variations in resources in the local environment. In particular, Life History Theory, a branch of evolutionary biology, suggests that a more favorable environment (high resources, low mortality) should trigger the expression of future-oriented preferences. In this paper, I argue that some of these psychological traits – a lower level of time discounting, a higher level of optimism, decreased materialistic orientation, and a higher level of trust in others – are likely to increase the rate of innovation. I review the evidence regarding the impact of affluence on preferences in contemporary as well as past populations, and conclude that the impact of affluence on neurocognitive systems may partly explain the modern acceleration of technological innovations and the associated economic growth.

1. Introduction

1.1. Two debates: The "Great Divergence" and the "Great Enrichment"

In the past 20 years, quantitative approaches to ancient societies have revealed a massive acceleration of economic growth in the eighteenth and nineteenth centuries (Broadberry 2018; Maddison 2007; Morris 2013). Although per capita income increased slowly, from $400 per year in early farming societies to $2,000 in early modern Britain (expressed in 1990 international or Geary-Khamis dollars), it has exploded in the past two centuries, reaching $40,000 in North America, Western Europe, and Eastern Asia. This increase is two orders of magnitude greater than any experienced before the Industrial Revolution. As Deirdre McCloskey writes: "in the two centuries after 1800 the … goods and services available to the average person in Sweden or Taiwan rose by a factor of 30 or 100. Not 100%, understand – a mere doubling – but in its highest estimate a factor of 100, nearly 10,000%, and at least a factor of 30, or 2,900%. The Great Enrichment of the past two centuries has dwarfed any of the previous and temporary enrichments" (McCloskey 2016a, p. 10).

What are the origins of modern growth? Two distinct debates are involved in addressing this question.

The first, traditional debate concerns the localization and the timing of the Industrial Revolution: Why did it occur in England? Why not in Holland, France, or China? What were the advantages of England? This is the debate about the "Great Divergence" (Pomeranz 2009) between Europe and Asia, and also about the "Little Divergence" (De Pleijt & Van Zanden 2016) between northwestern Europe and the rest of Europe. A range of solutions has been proposed to explain these two divergences: geography and the abundance of coal (Wrigley 2013), better institutions (Acemoglu & Robinson 2012; North & Weingast 1989), an early specialization in the textile sector (Allen 2009b), greater human capital (Kelly et al. 2014), the development of the Atlantic trade (Acemoglu et al. 2005), and more (for a recent review, see Van Neuss 2015).

In recent years, however, a second debate has emerged concerning the very nature of modern growth. This is the debate about the "Great Enrichment" (McCloskey 2016a). Why was growth limited in ancient societies? And how have modern societies been able to achieve such astonishing growth rates? Here, standard approaches to the Industrial Revolution are of little use (Clark 2007; McCloskey 2016a; Mokyr 2016). Even if these approaches can account for the temporary superiority of England in terms of institutions or human capital, they do not explain the discontinuity created by the Industrial Revolution, nor its magnitude. As Clark puts it: "What makes the Industrial Revolution so difficult to understand is the need to comprehend why – despite huge variation in the customs, mores, and institutions of preindustrial societies – none of them managed to sustain even moderate rates of productivity growth, by modern standards, over any significant time period. What was different about all preindustrial societies that generated such low and faltering rates of efficiency growth?" (Clark 2007, p. 207)

Recent work in economic history points to the central role of technology in modern growth (Mokyr 2009b; 2016). And indeed, what made England richer was a wave of inventions and innovations in the clothing industry, the mining industry, and so on. Newcomen and Watt invented the steam engine; Arkwright, Hargreaves, Crompton, and Cartwright revolutionized the textile sector; Darby and Cort found new ways to produce iron and more. To take but one example of the scale of these technological improvements, the amount of work needed to turn a pound of cotton into cloth went from the equivalent of 18 man-hours in the 1760s to 1.5 man-hours in the 1860s, an 1,200% increase in productivity. As Joel Mokyr (2009b, p. 5) writes: "The best definition of the Industrial Revolution is the set of events that placed technology in the position of the main engine of economic change."

One possible explanation for a high rate of innovation is the presence of well-functioning institutions (Acemoglu & Robinson 2012; North 1991). Since the work of Douglas North, it has been argued that the rate of innovation increased in England in the eighteenth century because institutions created a better incentive structure for potential innovators. According to the institutionalist approach, the English crown was more constrained by institutional rules and less likely to infringe on the property rights of innovators than its European counterparts (North & Weingast 1989). However, although the institutionalist approach may explain the exceptional political climate of eighteenth-century Britain, it is at odds with the history of the Industrial Revolution. The British institutions of the eighteenth century actually offered little to no incentive to innovate. The last significant reform of the patent system was in 1689, more than a hundred years before efficiency gains became common (Clark 2007), and, throughout the eighteenth century, innovators rarely made use of the patent system to defend their property rights (Mokyr 2009a). The invention of the flying shuttle is a case in point: "The flying shuttle was technically illegal because it saved labour, the patent was immediately pirated by competitors to little avail, and Kay was forced to move to France, hounded out of the country by angry weavers who threatened his property and even his life. Kay faced no special incentives – he even innovated *despite* some formidable social and legal barriers" (Howes 2016b).

One of the most puzzling facts about the Industrial Revolution is that many of the innovations did not require any scientific or technological input, and could actually have been made much earlier. Paul's carding machine, Arkwright's water frame, and Cartwright's improvements to textile machinery were not "rocket science" (Allen 2009b) and would not have "puzzled Archimedes" (Mokyr 2009b). Thus, the puzzle of the Industrial Revolution: If these innovations were so simple, why then did it take so long for many of them to emerge? As McCloskey puts it: "If the spinning jenny was such a swell idea in 1764 C.E., why was it not in 1264, or 264, or for that matter in 1264 B.C.E.?" (McCloskey 2010, p. 377).

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1.2. A Life History Theory approach to the puzzle of modern growth

Following a growing number of economic historians (Clark 2007; McCloskey 2006; 2010; 2016a; Mokyr 2009b; 2016), this paper proposes that the most important change that occurred during the Industrial Revolution may not have been in the incentive structure faced by innovators (e.g., better property rights, higher wages, larger markets), but in the preferences of individuals. Specifically, the sustained acceleration of the rate of innovation might partly be a result of a switch from a "scarcity mindset" to an "affluence mindset," which rendered people more patient, optimistic, and curious.

Why might there have been such a change in individual preferences at this time, in this place? In many parts of Eurasia, living standards slowly increased during Antiquity and the Middle Ages because of the gradual accumulation of technological knowledge in the industrial sector (Dutta et al. 2018). England, in particular, achieved an unprecedented level of affluence in the eighteenth century (Broadberry et al. 2015). English people at the time (in particular, members of the upper-middle class) were richer, healthier, taller, better nourished, better equipped, and better educated than individuals in any previous society (Allen 2001; Kelly et al. 2014). I hypothesize that this increase in living standards may have triggered a limited and gradual modification in neurocognitive processes such as time discounting, optimism, reward orientation, and trust. This hypothesis is based on Life History Theory (LHT), a branch of evolutionary biology that studies how organisms allocate their resources to different activities (development, reproduction, body maintenance, etc.) across the life span (Roff 1993; Stearns 1992). The basic idea of LHT is that organisms have a finite budget of resources and they must optimize the use of this budget across the life span. To do so, organisms must make trade-offs between different activities (growth vs. reproduction) and invest, at each moment in their lives, in the activity with the greatest marginal reproductive benefit. For example, if their risk of dying is high and their time horizon short, they should not invest in growing a large body or in developing a strong immune system but start reproducing as soon as possible (Charnov 1991; Promislow & Harvey 1990). LHT thus offers an explanation of why species living in different environments with different levels of resources may display drastically different physiological and behavioral traits (e.g., shorter or longer life spans, smaller or bigger bodies, lower or higher levels of investment in offspring).

Although Life History Theory was first developed to account for differences in life history across species (e.g., between species with shorter and those with longer life spans), it has been extended to account for differences in life history within the same species (Stearns & Koella 1986). In humans, recent empirical works has demonstrated that individuals tend to adopt different "life strategies" depending on their environment (Ellis et al. 2009; Figueredo et al. 2006; Frankenhuis et al. 2016; Pepper & Nettle 2017). In scarce environments, humans tend to grow faster, reach the age of sexual maturity earlier, reproduce earlier, and have more children. By contrast, in more favorable environments, humans adopt a different strategy, reaching maturity later, debuting sexuality later, and having a smaller number of children. These opposite "life strategies" are often referred to as "fast" and "slow" strategies (also called 'pace-of-life syndromes' or 'behavioral constellation') (see Fig. 1), although it should be emphasized that time preferences are one among many other preferences involved in life history strategies. Crucially, the environment also affects behavior and cognitive level: Individuals growing and living in scarce environments tend to be more violent (McCullough et al. 2013), more mistrustful of others (Petersen & Aarøe 2015), more materialistic (Carver et al. 2014), more likely to vote for an authoritarian leader (Safra et al. 2017), and more intolerant of deviance (Murray et al. 2011). Crucially, all of these traits are intercorrelated and indeed appear to be coordinated by a single underlying life history variable (Brumbach et al. 2009; Mell et al. 2018).

In this paper, I apply insights and results from work in LHT to explain the puzzle of the Great Enrichment. To innovate is inherently costly. It requires time and resources, more so as technological complexity increases (Bloom et al. 2017; Gordon 2012; Jones 2009; Mesoudi 2011). I argue that it is only in sufficiently affluent and stable environments that humans can afford to invest in activities whose benefits are delayed, unpredictable, or (at least initially) moderate. If this is true, then rising living standards are likely to influence the rate of technological innovation. As more people are able to satisfy their basic needs, they will become more patient, more optimistic, and more interested in exploring new technological solutions or in tweaking existing ones (see Fig. 2).

In what follows, I first present LHT in more detail and explain why becoming more exploratory and patient when resources are more abundant is adaptive (sect. 2). I then review the empirical evidence regarding the effect of affluence on human behavior (sect. 3). In particular, I show that resources can impact the expression of a range of psychological traits related to innovation: time discounting, self-control, optimism, cognitive exploration, and social trust. Finally, I review the evidence demonstrating the unprecedented level of affluence in eighteenth-century England (sect. 4) and discuss whether the English indeed displayed a "slow" psychology (in LHT terms) outside the domains related to innovation (sect. 5). I conclude the paper by discussing the points of convergence and divergence between this approach and other work emphasizing psychological mechanisms, as well as the potential of such a mechanism to explain the broader "civilizing process" (declining violence, declining impulsivity, increasing openness, increasing social trust; Elias 1982).

2. Life History Theory and the variability of innovativeness

2.1. The mechanism of adaptive plasticity

One common assumption in the social sciences is that biological mechanisms are fixed and, thus, cannot change. Historical change would thus require exogenous forces such as new ideas or new institutions. But this assumption is based on a common misconception about natural selection, which is wrongly thought to favor mechanisms that produce uniform and unchanging behaviors. In fact, most evolved mechanisms, physiological or psychological, actually come with a certain level of flexibility in response to local contexts. When the environment changes at a rate that is too high relative to generation time, natural selection does not have enough time to produce genetic adaptations for each and every environmental state (Moran 1992; Stearns & Koella 1986). In this case, natural selection instead favors a genotype that can react flexibly to the environment. Individuals are characterized not by a single phenotypic profile (organs, behaviors), but by what is called a "reaction norm": a range of phenotypes expressed conditionally depending on the current state of the environment. The expression of a variety of locally adapted phenotypes from the same genotype is called *adaptive plasticity*.

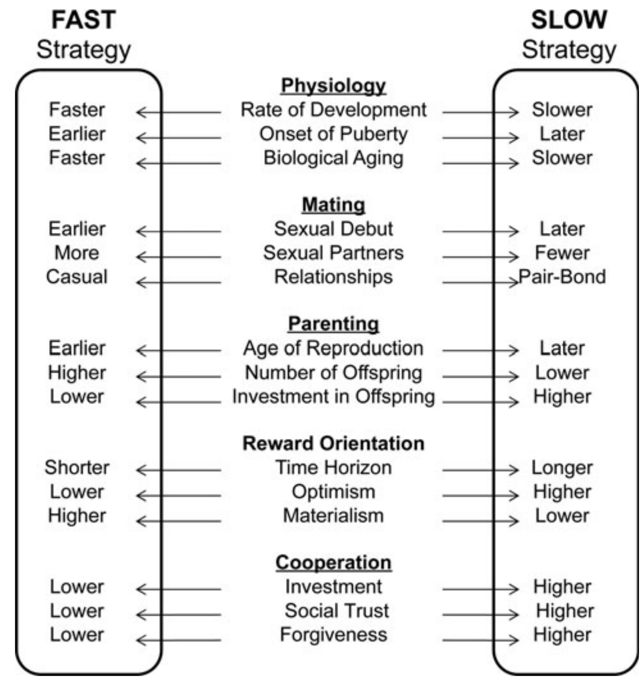

Figure 1. Fast and slow strategies. Adapted from Griskevicius (2013).

To take but one example, Bateson et al. (2015) tested the impact of scarcity on a population of starlings. Pairs of chicks were placed in nests where they faced either a high or low level of competition for 12 days as juveniles (Fig. 2a), after which they were all transferred to the laboratory for hand-rearing under uniform conditions. As expected, this manipulation affected the birds' telomeres, a biomarker of poor biological state and life expectancy. Birds in the high-competition condition traded their investment in growth and body maintenance for increased competitiveness. Impulsivity was measured when the birds were fully grown (6–12 months later) (Fig. 2b). Birds with greater developmental telomere attrition (those that reacted the most to the high-competition treatment) had a stronger preference for smaller but more immediate food rewards than birds with less developmental attrition or longer telomeres. A subsequent study from the same team found that biological aging in starlings is associated with higher levels of risk aversion (Andrews et al. 2018).

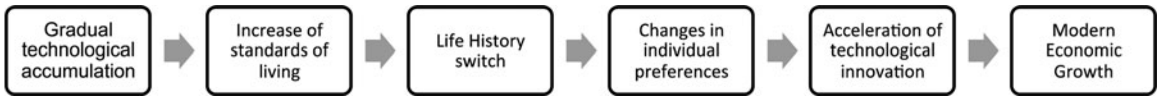

Figure 2. The causal role of the life history switch.

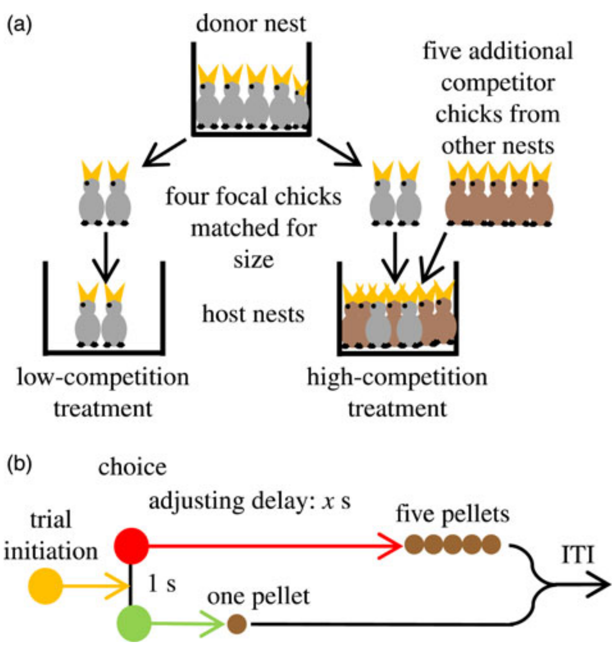

Figure 3. (a) Brood-size manipulation. The diagram shows the creation of a single family of four focal chicks. (b) Intertemporal choice task. One colored key (here, *green*) was assigned to the smaller sooner option (a 1-s delay to obtain one 45-mg pellet), and the other color (here, *red*) was assigned to the larger later option (a longer *x*-s delay to obtain five 45-mg pellets) (Bateson et al. 2015).

Bateson et al.'s experiment perfectly illustrates the potential of adaptive plasticity and LHT, in particular, to help us understand historical changes. When impulsivity was measured, the birds in the two groups were living the same life: They were fed the same way, lived in the same aviary, and were being taken care of by the same people. They also had the same kinds of social interactions with the same conspecifics. In other words, they were facing the same incentive structure with the same information about their environment. And yet their preferences regarding time differed according to how much they had been stressed when they were juveniles. Likewise, behavioral changes can occur without any change in political institutions, religious beliefs, or useful knowledge. They can result simply from change in adaptive calibrations.

2.2. Life history plasticity in humans

In the past decade, a range of studies has shown that human plasticity obeys the same evolutionary logic employed by other animals (see Fig. 1). When the environment deteriorates, individuals tend to accelerate their life history in every domain of life: reproductive investments, somatic investment, and social investment. In this section, I briefly review this literature.

2.2.1. Somatic investment

It is well documented that individuals growing up in a harsh environment are less likely to invest in their health. People in a lower socioeconomic position smoke more, exercise less, have a poorer diet, comply less well with therapy, use medical services less, and ignore health and safety advice more than their more-affluent peers (Nettle 2011; Smith & Egger 1993; Stringhini et al. 2010). The evolutionary reason is that health behavior competes for individuals' time and energy with other activities that contribute to their fitness. When resources are low, individuals invest less in their immune systems and in protecting their bodies (Nettle 2010b; Nettle et al. 2013) (see Fig. 3).

In line with this reasoning, Nettle (2014) showed that a lower level of parental support during childhood is associated with accelerated deterioration of health as well as increased levels of the C-reactive protein (an inflammatory biomarker of the somatic damage caused by social and environmental stressors). These associations are robust, persisting after adult socioeconomic position has been controlled for, and do not appear to be a consequence of an accelerated reproductive strategy, smoking, or body mass index. Similarly, Mell et al. (2018) showed that childhood poverty is associated with lower somatic investment (e.g., effort in looking after health) in a representative sample of French individuals. Crucially, Mell et al. showed that lower investments in health are associated with "faster" behaviors in the reproductive domain, supporting the existence of an overarching general life history strategy explaining both reproductive and health choices.

2.2.2. Reproductive investments

The basic prediction of LHT concerning reproduction is straightforward. As the level of resources decreases, investment in self-repair and bodily systems decreases (Nettle 2010b; Nettle et al. 2013). This, in turn, accelerates the speed of aging and lowers the optimal age for initiating reproductive effort. These predictions have been confirmed by a large number of studies: Humans living in harsh environments reach sexual maturity earlier (Brumbach et al. 2009; Ellis 2004), reproduce earlier (Belsky et al. 2010; Ellis 2004), and have more children (Guégan et al. 2001). Further studies have shown that people living in harsh environments also tend to invest less in their children. For example, using data from the British Millennium Cohort Study (N = 8,660 families), Nettle (2010a) showed that in harsher neighborhoods, breastfeeding duration is shorter, co-residence of a father figure is less common, and contact with maternal grandmothers is less frequent. Similar relations between environmental harshness and parental investment have been observed cross-culturally, with maternal care being inversely associated with famine, warfare, and high levels of pathogens (Quinlan 2007; Quinlan & Quinlan 2007).

2.3. Life history and attitude toward innovation

In the preceding sections, I reviewed the core domains studied by behavioral ecologists and evolutionary biologists working on LHT. However, in the last decades, scientists have started to apply the insights of LHT to a range of psychological domains that are likely to affect the rate of innovation.

2.3.1. Time discounting

Innovation takes time to yield benefits. Even where an individual is simply tweaking and adapting an existing invention (as was often the case of English innovators in the eighteenth century), individuals need to be ready to waste years trying to improve a device without knowing whether they will ever succeed. In his *British Industrial Revolution in Global Perspective*, Allen (2009b) discusses in detail the issues involved in inventing mechanical spinning (e.g., how much the speed should increase from one set of rollers to the next, how to arrange the gears to connect the main power shaft to the rollers and coordinate their movements, and the spacing between rollers). His discussion emphasizes that the most difficult part was not to come up with the idea of the roller, but to make the roller work in this application. Wyatt and Paul had spent decades on this problem but never succeeded, and it took several years for Arkwright and the clockmakers to find their solution. As Allen points out, many of the innovations of the eighteenth century involved what we would today call an "R&D program," in which the innovators constructed prototypes and performed careful experimentation.

How should time discounting be affected by increased living standards? From an LHT perspective, individuals living in a harsh environment cannot allocate resources to activities that have large but delayed benefits, because they cannot afford to wait (Houston & McNamara 1999). Thus, in a harsh environment, individuals are more likely to postpone investing in innovation and to focus on more pressing needs. By contrast, individuals surrounded by abundance can afford to invest in long-term endeavors such as building prototypes, conducting careful experiments, and trying out new models. Note that time discounting is a very abstract construct. People's time discounting will be visible not only in time-discounting tasks (i.e., $10 now rather than $20 later), but also in tests of psychological characteristics such as self-control and impulsivity. People living in affluent environments should show higher levels of self-control in tasks such as the marshmallow test or on questionnaires concerning impulsive actions.

2.3.2. Optimism

English innovators were particularly optimistic. As Howes (2016a) writes, they had an "improving mentality," seeing room for improvement everywhere. Henry Dircks, who improved steam engines and designed optical illusions, expressed the new mentality thus: "No work of art appears perfect to an enterprising mind. However simple its purpose, it may possibly be made lighter, stronger, more efficacious, or be done away with altogether. The man whose mind is thus constituted becomes an Inventor" (Dircks 1867, p. 9, cited in Howes 2016a, p. 8).

How should optimism be affected by increased living standards? LHT modeling, inspired by optimal foraging theory (Stephens 1981), suggests that individuals with low resources should have a high threshold for responding to reward cues because they have few resources to invest. As a result, they should be reluctant to initiate reward-approach behaviors (Nettle 2009a; Nettle & Bateson 2012). At the subjective level, they should feel that taking action will not be pleasurable, that they probably will not succeed, and that they do not have the energy to try. By contrast, individuals with high resources should be ready to initiate reward-approach behavior when given only minimal cues that a reward may be available. In humans, this state is associated with subjective feelings of optimism, with attentional biases toward reward-related stimuli and with willingness to try out novel reward-oriented strategies.

2.3.3. Materialism and intrinsic motivation

Edison famously observed that "invention is 1% inspiration and 99% perspiration" (cited in Allen 2009b, p. 149). In other words, innovation requires a high level of discipline and conscientiousness. Innovators need to focus on the many little challenges they face rather than on the big material rewards associated with developing a successful innovation. Thus, they need to be intrinsically motivated by the process of inventing, tweaking, and adapting existing technologies.

How should materialism and intrinsic motivation be affected by increased living standards? Individuals living in harsh environments are unlikely to invest in activities with a moderate return on investment because other, more vital activities need more urgently to be performed (Kenrick et al. 2010). It is only when they have fulfilled their vital and basic needs (food, self-protection, affiliation, social status) that they can afford to pursue activities such as free exploration. The predictions of LHT are somewhat well known, as they correspond to the "pyramid of needs" described by Maslow in the 1940s (Kenrick et al. 2010). What LHT does is explain why humans' needs are prioritized as they are. Individuals have all kinds of needs whose return on investment depends on the individual's state. When an individual is poor or young, some needs have a very high return on investment (food, self-protection, affiliation), and others have lower returns on investment (exploration: what Maslow lumped together with other activities under the heading of "self-actualization"). By contrast, when the same individual has fulfilled these needs (growing a body, making some friends), their return on investment diminishes (the marginal benefit of having an extra friend depends on the number of friends). Other activities, with a moderate return on investment, then start to be more advantageous. As a result, these activities become a priority.

2.3.4. Cognitive investment and cognitive exploration

The history of technology reveals that most macro-innovations came from outside of the field of the industry concerned (Allen 2009b, p. 141). They required innovators to ignore existing technological traditions and show little reverence for existing solutions. This was indeed the state of mind of many eighteenth-century innovators who were no experts in their industry and who discarded existing tradition. For example, Henry Bessemer (steelmaking process) explained that he was very aware of his ignorance and that he thought of it as an advantage:

> My knowledge of iron metallurgy was at the time very limited … but this was in one sense an advantage to me, for I had nothing to unlearn. My mind was open and free to receive any new impressions, without having to struggle against the bias which a lifelong practice of routine operations cannot fail more or less to create. (cited by Howes 2016b, p. 10)

What are the costs and benefits of individual and social learning? In behavioral ecology, social information is usually regarded as cheaper because individuals can piggyback on others' knowledge, but also as less accurate because individuals may not be in the same situation as others (Boyd & Richerson 1985; Laland & Williams 1998; Rieucau & Giraldeau 2011; Webster & Hart

2006). There is thus a trade-off between cost and accuracy. When resources are abundant, individuals should favor accuracy, be interested in cognitive investment and cognitive exploration, and thus be curious, independent, and open-minded. On the contrary, when resources are low, individuals should not waste more resources in exploring their environment; they should rather be conservative and conformist (Jacquet et al. 2018).

2.3.5. Social trust

Innovation is likely to be favored by social trust, which promotes open discussions and furthers the circulation of innovation (Mokyr 2016). As McCloskey notes, one important difference between Renaissance Florence and Early Modern Britain is that "Leonardo da Vinci in 1519 concealed his engineering dreams in secret writing," whereas "in 1825 James Watt of steam-engine fame was to have a statue set up in Westminster Abbey" (McCloskey 2016b, p. XXXIV). In line with this idea, Howes (2016a) showed that British innovators were almost all committed in some way to advancing, proselytizing, or disseminating further improvement by contributing to societies, authoring books, funding schools, or abstaining from patenting their inventions. Eighty-three percent shared innovation in some way; only 12% tried to stifle it, and only 5% are known to have been secretive.

From an LHT perspective, cooperation can be seen as an investment. Individuals invest their time and resources in collective action in the hope that these activities will produce bigger benefits than solitary work will (Baumard et al. 2013; West et al. 2007). From this perspective, cooperation is intrinsically forward-looking. It is thus expected that individuals should invest less in cooperation, and therefore be less trustful, when they cannot afford to lose their investment or when they discount time at too high a rate to wait for their partners to reciprocate.

2.4. Why innovation is not always the best strategy

LHT runs against the common sense according to which "necessity is the mother of invention." Common sense suggests that individuals in poverty should innovate more or show greater self-control, because they are in a situation where they would benefit more from innovating and restraining their impulses. And yet, clearly, innovation is more frequent in more affluent societies, those that already perform better. Even in nonhuman animals such as birds and monkeys, a growing body of data suggests that individuals are more innovative in captivity than in the wild (Forss et al. 2015; Haslam 2013; van Schaik et al. 2016).

The explanation for this paradox is that the opportunity costs of innovation are higher in poorer societies. Individuals living in poverty actually have more pressing needs than the need to innovate: they must find food for tomorrow, rebuild their house before the next rain, watch out for potential dangers, and so on. As counterintuitive as it may be, medieval laborers had better things to do than improve the productivity of their tools. If these laborers had invested in innovation, their fields might have been more productive in the long run. But the time spent on innovation, or the risks associated with tweaking traditional techniques, could also have led to the ruin of their families. Innovation is a luxury that few could afford in pre-industrial societies.

So, a lack of innovativeness should not be seen as suboptimal behavior. Exploration and exploitation are two different strategies with different advantages and drawbacks. Exploration can bring greater rewards in the form of profitable innovations, but it is often more risky in the sense that it requires time and resources and may not automatically lead to successful innovation. By contrast, exploitation brings lower rewards, but these rewards are safer because they require a lower level of investment and are more certain. Consequently, the potential benefits of exploration and exploitation are context-dependent. Exploration is a better strategy under conditions of relative safety, in which individuals can afford to divert some resources and even lose them in the pursuit of an innovation. Exploitation is a better strategy under harsh conditions, where any error can lead to starvation and death.

Importantly, this implies that individuals living in scarcity will not show impaired cognitive or behavioral performance. Instead, according to evolutionary theory, the preferences and behaviors of individuals should be contextually appropriate, and people living in scarcity are simply better adapted to that type of environment. Recall, here, that the stressed starlings were impulsive but not cognitively impaired. In line with this idea, individuals living in an environment of scarcity perform better at tasks related to actual challenges created by scarcity. Recent studies indicate that, compared with individuals living in affluent environments, people living in scarcity exhibit improved detection, learning, and memory in tasks involving stimuli that are ecologically relevant to them (e.g., dangers: Dang et al. 2016; Frankenhuis & de Weerth 2013; Frankenhuis et al. 2016; Mittal et al. 2015).

3. The impact of affluence on innovativeness

In section 2, I reviewed the theoretical evidence in favor of the view that an increase in resources is likely to affect a range of attitudes in a way that is conducive to innovation. In this section, I review the empirical evidence in favor of this view. In recent years, a number of scholars have demonstrated that poverty makes individuals more present-oriented, more loss-averse, less exploratory, and more conformist. In behavioral economics, these are often referred under the term "psychology of poverty" (Haushofer & Fehr 2014) or the "scarcity mindset" (Mani et al. 2013; Mullainathan & Shafir 2013). In this section, I focus on the other side of the coin, the "psychology of affluence" or the "abundance mindset," that is, evidence that affluence makes people more future-oriented, less loss-averse, more exploratory, and less conformist.

3.1. Time discounting, self-control, and impulsivity

Affluence has a substantial impact on time discounting. In a recent study, Haushofer and Fehr reviewed the effect of poverty on time discounting and showed that the level of resources has a strong effect on people's relationship to the future (Haushofer & Fehr 2014). For example, the discount rates of poor U.S. households are substantially higher than those of rich households (Lawrance 1991). Likewise, studies of Ethiopian farm households (Yesuf & Bluffstone 2008) and a South Indian sample (Pender 1996) have found that poverty is significantly associated with higher (behaviorally measured) discount rates.

People living in harsh environments where unemployment and violence are high also have less self-control and are more impulsive. Carver et al. (2014) studied the impact of harshness during childhood on self-control in adults. They used validated psychometric scales assessing self-control, urgency, and perseverance. Their results show a consistent association between childhood harshness and lack of self-control. Similarly, Duckworth et al. (2013) demonstrated that negative life events in the past year (events such as getting fired or laid off from job, "major change in emotional closeness of family," or divorce) were associated with diminished self-control in children and adolescents. In line with these results, poverty (i.e., inadequate housing, economic insufficiency) is associated with higher resting levels of salivary cortisol during the first four years of life which, in turn, is associated with worse performance on executive function tasks (Blair & Raver 2012; Blair et al. 2011).

3.2. Optimism and feeling of internal control

Studies with large cohorts have demonstrated a strong socioeconomic status (SES) gradient in optimism and pessimism, with higher SES being associated with higher optimism scores and lower pessimism scores (Boehm et al. 2015; Heinonen et al. 2006; Robb et al. 2009). Importantly, in line with the idea that part of life history is calibrated early in childhood, childhood family SES has been found to be associated with overall optimism and pessimism component scores, even after controlling statistically for SES in adulthood (Heinonen et al. 2006). A number of other psychological variables are related to optimism, such as "locus of control" and "self-efficacy," which measure people's confidence in their ability to control their environment. To test the association between poverty and locus of control, Haushofer (2013) used questions from the World Values Survey such as: "Some people believe that individuals can decide their own destiny, while others think that it is impossible to escape a predetermined fate. Please tell me which comes closest to your view on this scale on which 1 means 'everything in life is determined by fate,' and 10 means that 'people shape their fate themselves.'" Both within and across countries, affluence is associated with a higher feeling of internal control. This study replicates previous studies in a diversity of populations (e.g., Kiecolt et al. 2009; Lundberg et al. 2007; Poortinga et al. 2008).

3.3. Materialism and intrinsic motivation

Materialism is typically understood as "the belief that it is important to pursue the culturally sanctioned goals of attaining financial success, having nice possessions, having the right image (produced, in large part, through consumer goods), and having a high status (defined mostly by the size of one's pocketbook and the scope of one's possessions)" (Kasser et al. 2004). Using longitudinal data on American twelfth graders between 1976 and 2007 ($N = 355{,}296$), Twenge and Kasser (2013) measured materialism (through questions measuring young people's attitudes on "how important it is 'to have lots of money'" or to have "a job which provides you with a chance to earn a good deal of money"). In line with LHT, they showed that societal instability was associated with higher levels of materialism (for similar results, see Briers et al. 2006; Cohen & Cohen 1996; Kasser et al. 1995; Sheldon & Kasser 2008). Carver et al. (2014) studied another kind of extrinsic goal, namely, social success. Using a scale measuring hubristic pride, popular fame, and financial success, they showed that childhood adversity is associated with a greater tendency to set implausibly high goals ("I will be famous," "I will run a Fortune 500 company"). Finally, sensation seeking is another behavioral construct that is related to intrinsic motivation. Carver et al. (2014) showed that childhood adversity is associated with higher levels of sensation seeking, as well as greater consumption of illicit drugs and alcohol (Droomers et al. 1999; Legleye et al. 2011).

At the other end of the spectrum, affluence has been shown to positively impact intrinsic motivation: As people get richer, they are less interested in immediate material rewards. Using the World Values Survey, Haushofer (2013) showed a consistent association between intrinsic motivation and income, both across and within countries (Haushofer approximated intrinsic motivation with two questions: agreement with the statements "Working for a living is a necessity; I wouldn't work if I didn't have to" and "I do the best I can regardless of pay" (Haushofer 2013). Affluence has also been found to affect personality consciousness (Akee et al. 2018). Using the Great Smoky Mountains Study of Youth, Akee et al. (2018) demonstrated that cash transfers increased conscientiousness and reduced drug consumption independently of income or education.

3.4. Cognitive investment and cognitive exploration

Individuals with low resources should invest less in cognitive exploration and information gathering, and, consequently, they should rely more on cheaper sources of information such as others' opinions (Nettle 2019). Jacquet et al. (2018) studied the calibration of cognitive investment in information gathering through variables such as childhood scarcity and childhood unpredictability (assessed through agreement with statements such as "Things were often chaotic in my house" and "People often moved in and out of my house on a pretty random basis"). The results indicated that, independent of their current situation, participants who experienced scarcity and unpredictability during childhood are more likely to follow the opinion of the group in a standard face evaluation task.

Affluence should also impact cognitive investment in more abstract tasks. In a series of experiments, Mani et al. (2013) studied the impact of scarcity on individuals' performance in Raven's Progressive Matrices and in a spatial compatibility task. They induced richer and poorer participants to think about everyday financial demands. They hypothesized that for the rich, these little financial demands would be of little consequence, whereas for the poor, these demands would trigger persistent and distracting concerns. In line with their hypotheses, poor participants performed worse. Mani et al. (2013) also conducted a field study that used a quasi-experimental variation in actual wealth. Indian sugarcane farmers receive income annually at harvest time and find it hard to smooth their consumption. As a result, they experience cycles of poverty: they are poorer before harvest and richer afterward. (On average, farmers had 1.97 more loans before harvest than they did afterward. They were also more likely to answer "Yes" to the question, "Did you have trouble coping with ordinary bills in the last fifteen days?" before harvest than after). This allowed the researchers to compare the cognitive capacities of the same farmer in poorer (preharvest) versus richer (postharvest) circumstances. Again, the farmers' performance was worse in times of scarcity.

3.5. Trust

Cooperative behaviors have been found to vary with the harshness of the environment (Holland et al. 2012; Nettle et al. 2011; Silva & Mace 2014; 2015; but see Wu et al. 2017). Independent of their current level of resources, people who grew up in a deprived environment are more likely to defect (McCullough et al. 2013), more likely to steal from others (Schroeder et al. 2014), and less likely to forgive others (McCullough et al. 2013; Pedersen et al. 2014), trust them (Mell et al. 2018), and punish cheaters (Schroeder et al. 2014). Importantly, life history theory predicts that cooperative behaviors should be part of a more general life history strategy. In line with this prediction, Petersen and Aarøe (2015) report an association between low birth weight, low self-control in childhood, and lower social trust in adulthood (on the early calibration of prosociality, see also Benenson et al. 2007; Safra et al. 2016). Similarly, lab studies show a correlation between high time discounting – an indicator of a faster life strategy – and low levels of cooperation in economic games (Curry et al. 2008; Espín et al. 2012; Harris & Madden 2002; Kocher et al. 2013; Kortenkamp & Moore 2006). Finally, Mell et al. (2018) demonstrated that the impact of environmental harshness on social trust is mediated by a latent psychological construct corresponding to life history strategy.

3.6. Assessing the causal impact of affluence

Most studies presented in this section are correlational, and it could be that the association between affluence and a slow life history is driven by other factors (notably genetics). Similarly, experimental studies may reveal real but fleeting effects on human behaviors. However, in recent years an increasing number of studies in econometrics have aimed to assess the causal impact of the environment using natural experiments. There is now a consensus that exogeneous shocks in utero or during early childhood (disease, famine, malnutrition, pollution, war) have dramatic, long-lasting effects on physical and mental health, height, IQ, and income (for a review, see Currie & Vogl 2013). A growing number of studies show similar effects on psychological traits such as risk attitudes (Moya 2018), materialism (Kesternich et al. 2015), and prosociality (Cecchi & Duchoslav 2018; Gangadharan et al. 2017). The Great Smoky Mountains Study of Youth (cited in sect. 3.3) is a case in point. This study takes advantage of the opening of a casino in the Eastern Band of Cherokee Indians tribal reservation. Following the opening of the casino, permanent transfers were provided to all adult Cherokees (but not to non-Cherokees living in the same area), regardless of employment conditions, marital status, presence of young children in the household, or residence on the reservation. Comparing Native American children with non-Native American children before and after a casino opened on tribal land, Akee et al. (2018) found that receipt of casino payments reduced criminal behavior, drug use, and behavioral disorders associated with poverty such as depression, anxiety, and oppositional disorders, and it also increased agreeableness (i.e., the tendency to be cooperative and get along well with others) and conscientiousness (i.e., the propensity to be hard-working and organized). Similarly, Hörl et al. (2016) used the hunger episode in occupied Germany after WWII as an instrument to test the effect of an exogenous variation in caloric input in childhood on social trust in adulthood. They found that individuals exposed to lower caloric input in 1944–1945 showed decreased social trust later in life. Twin studies offer another way to disentangle the causal impact of genetic and environmental factors. Using this method, Cronqvist et al. (2015) found that individuals with higher birth weight (within pairs of identical twins) are more likely to participate in the stock market (a proxy of risk-taking preference).

To conclude, levels of resources shape individual preferences in a predictable way. Individuals living in conditions of affluence tend to have lower rates of time discounting, to be more optimistic, and to be more conscientious and trustful. But why should this set of preferences be found in eighteenth-century England more than in another place and time? Why were the English the first people to lose the "scarcity mindset" and embrace the "affluence mindset"?

4. The unprecedented affluence of eighteenth-century England

It has long been thought that living standards and GDP per capita were more or less stagnant before the Industrial Revolution (Clark 2007). This was based on the Malthusian assumption that any per capita income above some subsistence level would lead to population increases and, consequently, to a decrease in per capita income. However, the Malthusian reasoning is based on the false premise that all innovations should occur in the agricultural sector and should translate into an increased quantity of calories. This is sometimes true – as, for example, during the Neolithic Revolution – but not always. In many cases, in sectors such as clothing, construction, and luxury goods, innovations do not automatically increase the quantity of available calories but instead increase some other aspect of living standards (Dutta et al. 2018).

Recent work in historical economics and quantitative history confirms this conclusion and demonstrates that some societies – Classical Greece, Roman Italy, Song China, Medieval Italy – experienced some period of growth (Allen 2001; Maddison 2007; Morris 2013; Ober 2015). Here, I review the evidence concerning the growth of purchasing power, GDP per capita, urbanization, and health. The evidence leads to three conclusions: (1) England enjoyed a long period of growth in living standards from the fifteenth century on; (2) England was richer than any other country, in Europe or elsewhere, on the eve of the Industrial Revolution; and (3) England was richer than any previous society in the history of humanity, including Classical Greece, Roman Italy, Song China, and Medieval Italy.

4.1. Purchasing power

Allen's (2001) seminal work on pre-modern European wages clearly demonstrated that English (and Dutch) workers were much richer than their European counterparts. There was little difference in 1400, but over the following centuries welfare ratios increased in England and The Netherlands and decreased in the rest of Europe. (The welfare ratio is the average annual earnings divided by the cost of a basket of goods necessary for the minimal subsistence of a family of four. A welfare ratio greater than one indicates an income above the poverty line, whereas a ratio less than one means the family is in poverty.) In 1750, the welfare ratio of English craftsmen was 2.21, compared with 1.20 in Paris and 0.97 in Florence. Similarly, the welfare ratio of English laborers was 1.58, versus 0.80 in Paris and 0.90 in Florence (Allen 2001; but see Malanima 2013; Stephenson 2017). Later studies have found that the welfare ratios of Chinese, Indian, and Japanese workers were similar to continental European welfare ratios and much lower than those of the English and the Dutch (Allen et al. 2011; Deng & O'Brien 2016). Using Diocletian's Price Edict (301 AD), Allen (2009a) reconstructed the welfare ratio of Roman workers. His estimation points toward a very low welfare ratio, lower than eighteenth-century European and Asian welfare ratios (see Fig. 4). Similar work confirms that workers in ancient economies, even at the peak of the Roman

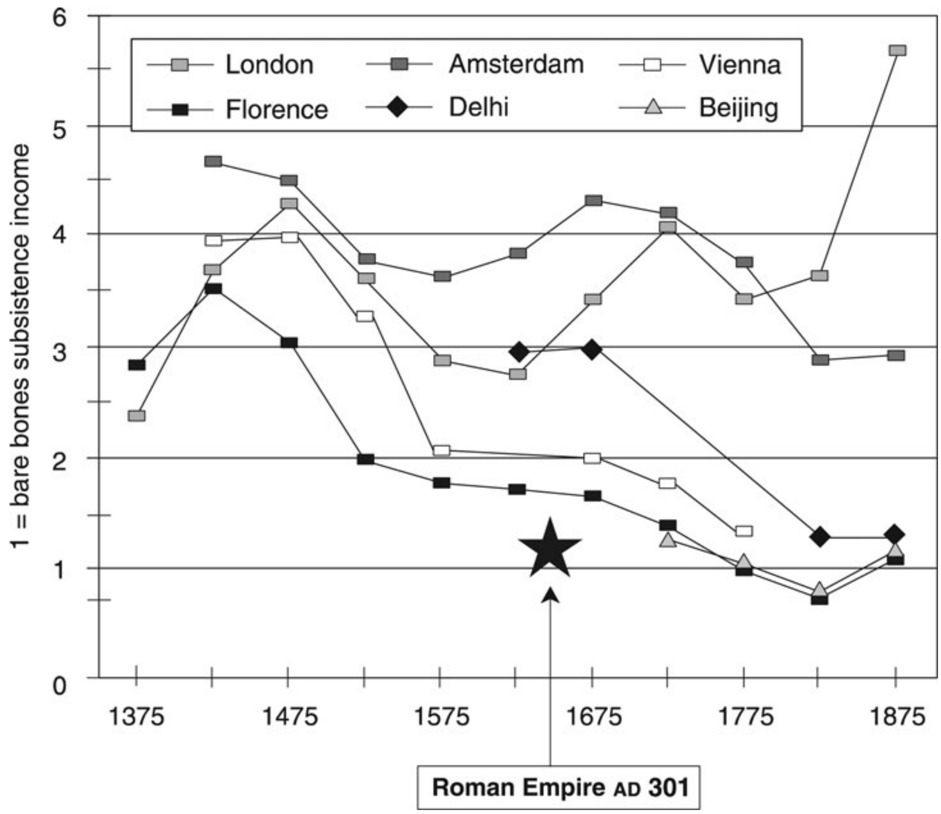

Figure 4. Welfare ratios of laborers in Europe, Asia, and the Roman Empire (Allen 2009a).

Empire, were probably much poorer than their eighteenth-century English counterparts (Scheidel 2010).

English purchasing power at that time has probably been underestimated, partly because it is difficult to compare luxury goods (furniture, sweets, etc.) across countries and across time. However, it is likely that luxury goods played an important but hidden role in increasing the living standards of the English (De Vries 1994; Hersh & Voth 2009; Morris 2013). For example, Hersch and Voth (2009) estimated in a recent paper that the introduction of sugar and tea transformed the English diet in the eighteenth century and increased the welfare of the English by 15%, a gain much larger than those associated with the introduction of the Internet (2%–3%) or mobile phones (0.46%–0.9%). Including tomatoes, potatoes, exotic spices, polenta, and tobacco would show an even larger increase in living standards in eighteenth-century England. During the same period, technological products became much more widely available in England. Nordhaus (1996) famously examined the history of lighting to show that previous studies on the evolution of living costs had vastly underestimated the decline in the cost of many goods. For example, in a recent paper Kelly and Ó Gráda (2016) showed that, during the eighteenth century, the real price of watches fell by an average of 1.3% a year, equivalent to a fall of 75% over a century (Kelly & Ó Gráda 2016). Peter King's study on a small number of English paupers' inventories shows that, in 1700, they rarely possessed clocks, books, candlesticks, lanterns, fire jacks, or fenders. A century later, paupers were materially better provided for than the middle class of a century earlier (King 1997). Just as in the case of the colonial goods referred to above, the impact of these new products on people's welfare is probably underestimated. Dittmar (2011) found that the welfare impact of the printed book was equivalent to 3%–7% of income by the 1630s (again exceeding similarly measured welfare effects associated with the Internet or mobile phones).

Including luxury goods thus increases the estimate of growth in living standards in eighteenth-century England (Clark 2007, p. 255). It also increases the gap between England and the rest of the world. For example, in 1800, the average English individual consumed 10 times as much sugar as the average French individual and 20 times as much as individuals living elsewhere in Europe (De Vries 1994; Hersh & Voth 2009). In a recent paper, Lindert (2016) argued that because of a range of biases in previous estimates, including the difficulty of including luxury goods, the difference between England and the rest of the world was even bigger. His new estimates suggest that purchasing power per capita in England was already higher than in Italy by the beginning of the sixteenth century. At the onset of the Industrial Revolution (in 1775), it was 75% higher than in Italy and 100% higher than in France (in 1820, the earliest year for the England/France comparison). Differences with respect to non-European economies were even larger: In 1750, purchasing power per capita in England was 300% that of Japan; in 1595, it was 280% that of India (the only year for which data are available before the Industrial Revolution); and in 1840 (the earliest year for the England/China comparison), it was 280% that of China. Book consumption confirms this pattern: In 1750, Chinese, Japanese, and Indian book consumption was one-tenth to one one-hundredth of British consumption (Buringh & Van Zanden 2009; Xu 2017).

Finally, recent work by Humphries and Weisdorf (2016) suggests that the rise in English wages has been underestimated because of the use of daily wages instead of annual wages. Using income series of workers employed on annual rather than daily contracts shows that incomes rose continuously from 1650, that is, a century before the onset of the Industrial Revolution.

4.2. GDP per capita

In an influential study, Stephen Broadberry and colleagues reconstructed the British economy over the past 800 years. Their work suggests that England experienced a continuous period of growth from the thirteenth century ($711 per capita in 1280) to the eighteenth ($2,097 in 1800). This continuous growth contrasts with the absolute decline of other affluent societies of the time such as China (from $1,032 in 1400 to $597 in 1800) and Italy ($1,477 in 1500 to $1,243 in 1800). More important, English GDP per capita in 1800 was higher than those of all European countries (with the exception of The Netherlands) and much higher than those of non-European countries such as China ($723), Japan ($640), and India ($573) (see Fig. 5). Although Pomeranz (2009) famously argued that there is little sense in comparing China as a whole with England, a small part of Europe, recent studies show that even the wealthiest parts of China, such as the Yangtze Delta, were much poorer than England at the time of the Industrial Revolution ($988 in 1840 vs. $2,718 for Britain in 1850; Li & Luiten van Zanden 2012). Reconstructions of ancient economies also suggest that English GDP at the time was higher than that of Roman Italy at its peak (estimates range from $820 to $1,400), Abbasid Iraq ($940), Song China ($1,006 in 1020 under the Songs), or medieval Italy ($1,596) (Broadberry et al. 2018; Cascio & Malanima 2009; Malanima 2011; Pamuk & Shatzmiller 2014; Scheidel & Friesen 2009).

4.3. Urbanization rate

The rate of urbanization is also a good indicator of economic development (Jedwab & Vollrath 2015). Using Bairoch's database with a threshold of 10,000 inhabitants, Bosker et al. (2013) showed that England was urbanizing at a high rate in the early modern period, going from 2.1% of its population living in urban settlements in 1500 to 23.14% in 1800. Similarly, Scotland went from 3.6% in 1500 to 17.3% in 1800 (see Fig. 6). In the same period, the urbanization of China or Italy was rather stagnant (Xu et al. 2015). More important, the urbanization rate of England in 1800 (23%) was much higher than in all other societies in 1800, with 4% in China (but 15% in the Yangtze Delta), 9% in France, 13% in Japan, and 17% in Italy and Iraq (Bassino et al. 2015; Bosker et al. 2013; Xu et al. 2015). From a historical perspective, few societies had ever been as urban as England was at the beginning of the Industrial Revolution. Although the rate of urbanization in ancient Greece and Rome was extremely high for ancient societies, it is estimated that it was about 16% in Classical Greece and 20% in Roman Italy (the latter mostly because of the size of Rome; Bowman & Wilson 2011; Ober 2015).

4.4. Health

Biological indicators also suggest that England enjoyed steady growth in living standards before the Industrial Revolution. A range of approaches, using the genealogy of the British royal family (David et al. 2010), the genealogy of European nobility (121,524 individuals between 800 and 1800; Cummins 2017), the Index Bio-Bibliographicus Notorum Hominum (300,000 individuals before 1879; De la Croix & Licandro 2015), and Wikipedia (Gergaud et al. 2017) point toward the same result: Life expectancy was on the rise in Europe from 1650 onward. More important, life expectancy in northwestern Europe was higher than in the rest of Europe from 1000 AD onward, and it continued to rise at a higher rate than in the rest of Europe from 1450 onward (Cummins 2017). As a result, life expectancy on the eve of the Industrial Revolution was 42.1 years in England and Wales, compared with 24.8 years in France, for example (Wrigley 1997). In line with these data, Kelly and Ó Gráda (2014) show that although the positive check – in the sense of the short response of mortality to price and real wage shocks – was powerful in the Middle Ages, it had weakened considerably in England by 1650, unlike in France. Similarly, the last widespread, killing famine occurred in 1597 in southern England and in northern England in 1623. By contrast, the last famine occurred much later in the rest of Europe: in 1710 in France, in 1770 in Germany, Scandinavia, in 1770–1772 in Switzerland and in 1866–1868 in Finland (McCloskey 2016a). Even bigger contrasts can be observed when comparing England with Asian countries (Clark 2007).

Other biological indicators, such as nutrition and height, confirm this difference. In a recent study, Kelly and Ó Gráda (2013) estimated that the English in 1750 consumed an average of 2,900 kcal per day, whereas the French consumed only 1,700 to 2,000 (Fogel 1964; Kelly & Ó Gráda 2013). The effects of better nutrition are most obviously noticeable in the differences in the height of adult males. For cohorts born between 1780 and 1815, comparisons suggest that the gap between French and English heights on the eve of the Industrial Revolution was more than 5 cm (Nicholas & Steckel 1991; Weir 1997).

4.5. The impact of affluence on upper tail human capital

So far, I have discussed the living standards of the average individual in England, but a growing literature has been documenting the role of an elite of skilled artisans and merchants – the "upper tail of human capital" – in driving technological progress and economic development (Mokyr 2016; Squicciarini & Voigtländer 2015). In seventeenth- and eighteenth-century England, for example, merchants, lawyers, and capitalists were overrepresented among innovators. They made up 4.6% of the population but accounted for 32.8% of inventors (Allen 2009b). This suggests that what matters for economic development is the emergence of a dynamic urban upper middle class.

Of course, skilled elites had existed for a long time before the Industrial Revolution, in Athens, Rome, and Florence. So, what set eighteenth-century England apart from previous societies? The data reviewed below suggest that eighteenth-century English society was simply more affluent than any of those previous societies. This greater affluence had two consequences. First, it increased the absolute number of individuals displaying a slower strategy and, thus, the pool of potential innovators. In other words, the upper tail of human capital was bigger, and it ran further than in previous societies. Not only were the English elites richer, but also all social classes were comparatively more affluent than in any previous society (see Milanovic et al. 2011 on pre-industrial inequality). As we have seen, bad harvests ceased to increase mortality rates, first for the elite and then for everyone; life expectancy increased, again first in the elite but soon in the middle class as well; and data on literacy suggest that lower-class English individuals were actually more educated than upper-class Romans (see sect. 4.2).

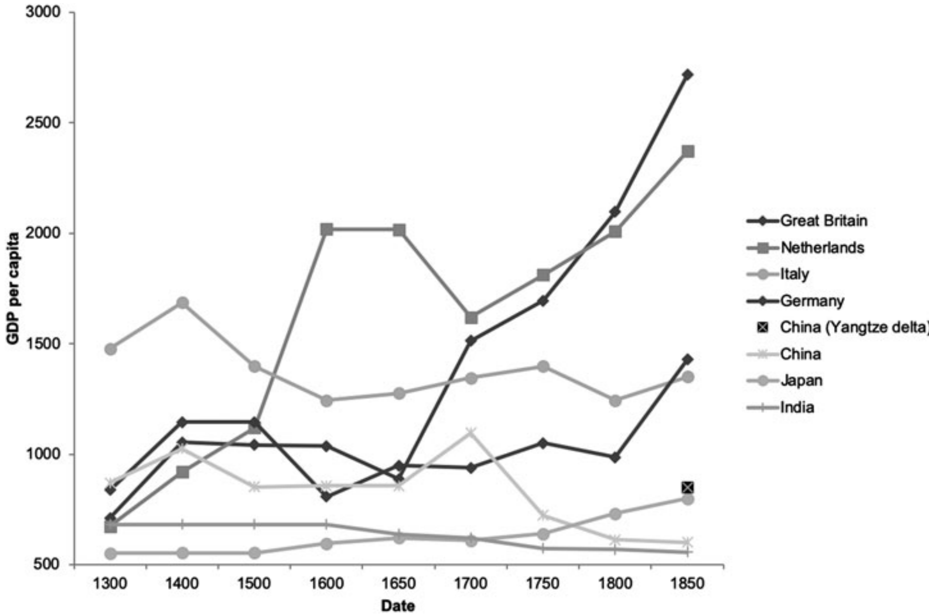

Figure 5. GDP per capita in 1990 international dollars. Adapted from Broadberry (2018) for China, Japan, Italy, Great Britain and the Low countries, from Pfister (2011) for Germany, and from Ridolfi (2017) for France.

The second consequence of this English affluence is that the proportion of people displaying a slower strategy was also higher. This means that the levels of social trust, tolerance, and optimism expressed by the average English citizen were higher than elsewhere. This is likely to have had consequences at the global level in terms of interpersonal violence, governance, and even public health, for the simple reason that better-fed people invest more in their immune system and are less likely to transmit pathogens, including to the upper classes (for a discussion about the consequences of poverty on the psychology of the upper class, see Wilkinson & Pickett 2010; Nettle 2017). Even the circulation of information is likely to be affected, because anxious people tend to focus on, believe, remember, and spread negative information to a greater extent (Fessler et al. 2014; Rudaizky et al. 2014). This means that, with the same absolute level of material resources, upper-class English individuals in the eighteenth century lived in a better social, political, and biological environment than their fifteenth-century Florentine or first-century Roman counterparts, just because the individuals around them were better fed, healthier, better educated, less violent, and more tolerant.

5. Life History Strategy of the eighteenth-century English

As we saw in section 1, LHT suggests that the environment triggers a set of coordinated behaviors, a global life history strategy. In a recent article, Pepper and Nettle (2017) coined the term "behavioral constellation of deprivation" to refer to the set of behaviors associated with poverty (e.g., early reproduction, low investment in health, present orientation). In the same way, people living in affluent environments should display a "behavioral constellation of affluence": late reproduction, higher investment in health and cognitive skills, higher levels of trust and cooperation, and a more future-oriented attitude. This last section will examine whether the eighteenth-century English indeed displayed this "behavioral constellation of affluence."

Obviously, direct measurement of individual behaviors and preferences in the eighteenth century is impossible (at least given current technology, scientists are starting to measure stress through cortisol analysis in archaeological hairs; see, e.g., Webb et al. 2010). But a range of indirect evidence is available concerning violence, self-discipline, and long-term investment in human capital. In fact, Norbert Elias had already shown in *The Civilizing Process* (1982) that from the late Middle Ages on, Europeans, and in particular northwestern Europeans, displayed lower levels of violence, decreasing impulsivity, higher literacy levels, and greater sensitivity to the psychological states of others – in short, a slower life strategy.

5.1. Reproduction and fertility rates

Although the demographic transition has been thought to have occurred quite late in England (at the end of the nineteenth century), long after the Industrial Revolution (Wrigley & Schofield 1983), new studies show that, starting with the generation that married in the 1780s, there was a significant decline in net fertility among the middle and upper classes in England (Clark & Cummins 2015). Although rich men tended to have more children than poor men before 1780, at this point, they switched from a net fertility of more than four children to one of three or fewer, no different than the general population. This large change in behavior had been hidden in aggregate English data, because at the same time the net fertility of poorer groups (the majority of the population) increased to equal that of the rich. This rapid transition from a fast reproductive strategy to a slow reproductive strategy seems to have started as early as 1780, *in parallel* to the Industrial Revolution. Crucially, and in line with LHT, it does not seem to have been driven by economic factors such as an increase in returns on investment in education or in children's wages (Clark & Cummins 2015), but rather by changes in attitudes in the wealthiest part of English society.

5.2. Somatic investment and human capital

LHT holds that individuals living in an affluent environment should invest more in their soma, that is, in both their body and their skills (see sect. 2.2.1). I already noted in section 4 that

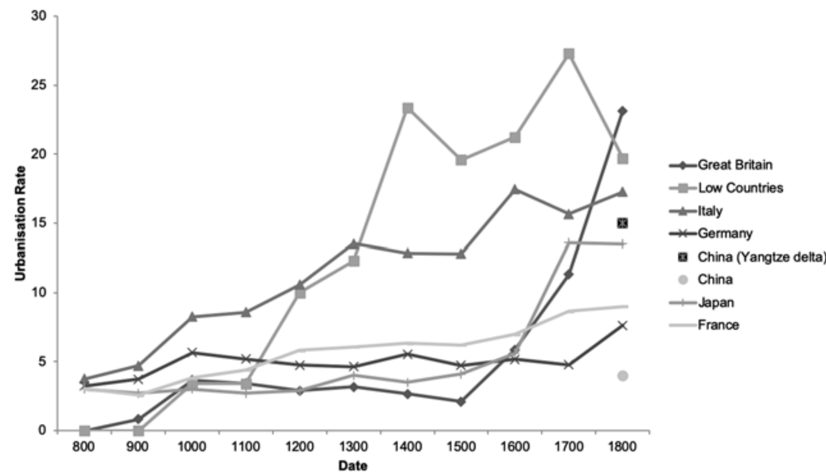

Figure 6. Urbanization rate. Sources: Bassino et al. (2015), Bosker et al. (2013), Xu et al. (2015).

the English were taller than their European counterparts, a clear cue that they indeed invested more in their soma (on muscular strength; see Kelly et al. 2014). Regarding investment in cognitive skills, English literacy clearly increased greatly between 1500 and 1750, as England shifted from a society of illiterates to one where half of all individuals could at least sign their names (Stephens 1990). Although England was behind The Netherlands and Scandinavia, it was clearly ahead of other continental countries on the eve of the Industrial Revolution. For example, although only 39% of men and 19% of women were literate in France in 1750, the figures in England were 61% of men and 37% of women (Henry & Houdaille 1979; Schofield 1973).

The study of numeracy through age heaping shows similar patterns: English numeracy increased from 1500 onward, and it was higher in 1750 than in most European countries, with the exception of Germany and Scandinavia (A'Hearn et al. 2009) (age heaping is the tendency of innumerate people to round their age to the nearest 5 or 10 and is a convenient sign of numeracy in historical documents). Indirect evidence suggests that levels of numeracy in England were also much higher than in India, China, or Japan (Baten et al. 2010; Clark 2007), as well as in ancient Rome (Clark 2007). For example, the study of age heaping in English, Italian, and Roman censuses reveals that the poor in England around 1800 had more age awareness than officeholders in the Roman Empire (Clark 2007). Another indicator of literacy and investment in human capital is the consumption of books, again much higher in England than in other European countries (Baten & Van Zanden 2008; Buringh & Van Zanden 2009).

What is striking about this high level of investment in human capital is that it cannot be explained by direct incentives. As Clark (2007) notes: "We find absolutely no evidence as we approach 1800 of any market signal to parents that they need to invest more in the education or training of their children" (p. 225). The skill premium in the earnings of building craftsmen relative to unskilled building laborers and assistants was actually lower in eighteenth-century England than in fourteenth-century England, and it was lower than in other European and non-European countries (Van Zanden 2009). Clark concludes: "If there was ever an incentive to accumulate skills it was in the early economy" (Clark 2007, p. 181).

5.3. Prosociality and violence

From a life-history perspective, as the environment improves, individuals should invest increasingly in cooperation (see sect. 2.3.5). The behavior of the English in the eighteenth century seems to have fit this prediction. Data on homicide rates show that the worldwide decline in violence started in England. In the sixteenth century, the homicide rate in England was about 7 per 100,000 inhabitants, versus 25 in the Netherlands, 21 in Scandinavia, 11 in Germany, and 45 in Italy. On the eve of the Industrial Revolution, although the gap had decreased, England was still ahead of the rest of Europe, and indeed the world (Eisner 2003; Pinker 2011a).

Although it must be tempting to think that this decline of violence resulted from the development of the police force and the penal system, evidence shows that they are uncorrelated (Eisner 2003; Pinker 2011a). One reason is that official authorities long treated homicide leniently, as the result of passion or a defense of honor (Eisner 2003). Another relevant fact is that the decline of violence occurred in the same way both in the absolutist regime of Tudor England and in the decentralized Dutch Republic. Similarly, although the police forces in medieval and early modern Italy were particularly large compared with those in England, Sweden, and The Netherlands, levels of violence remained very high in Italy until the end of the nineteenth century (Eisner 2003).

Therefore, people did not stop killing each other for fear of an increasing level of punishment. They rather stopped killing each other because their reaction to offenses and insults became less violent (Eisner 2001), that is, because their psychology became more and more cooperation-oriented. In line with this idea, attitudes toward capital punishment, slavery, judicial torture, and dueling also changed at the same time in Europe. Slavery is a case in point here; it has been shown that slavery was not abolished in response to economic (selfish) incentives, but rather as a result of intense public campaigns based on moral and emotional arguments (see Wedgewood's famous "Am I not a man and a brother?" plate; Carey 2005; Davis 1999). It is noteworthy that on all of these moral issues, England led the trends throughout the eighteenth century (Eisner 2003; McCloskey 2016a; Pinker 2011a). More generally, eighteenth-century Europe was clearly ahead of non-European societies as well as ancient societies such as Athens and Rome, which tolerated or even celebrated much higher levels of violence (Pinker 2011a).

Other indicators, such as the flourishing of societies and associations (Clark 2000; Sunderland 2007), suggest that the English were more prosocial and more trusting than other populations in the eighteenth century. Thus, in the sixteenth and seventeenth centuries, England was the first state to implement a system of poor relief. By the end of the seventeenth century, Poor Law expenditure was about 1% of GDP, and it was sufficient to provide complete subsistence for 5% of the population. By the end of the eighteenth century, it further increased to about 2% of GDP (Kelly & Ó Gráda 2014). Kelly and Ó Gráda (2014) argue that the system was effectively able to minimize outright starvation. In line with this idea, the link between harvest failure and crisis mortality progressively vanished after the midseventeenth century. Other European countries took much longer to implement such a large-scale system of poor relief.

5.4. Preferences involved in innovativeness

So far, we have explored the standard predictions of LHT. But LHT also predicts that the eighteenth-century English should also have been more patient and optimistic, and less materialistic. These behaviors are obviously harder to observe and quantify than reproduction and somatic investment. But does the evidence point in the right direction?

5.4.1. Time discounting

Measuring self-discipline is difficult, but literacy could be seen as an indirect indicator. As Eisner (2014) notes, "reading and writing are in themselves training sessions in self-control. They require mastery over abilities such as sitting still, fine-motor control of hand movements, self-directed information processing, and training of mnemonic and thinking skills – all of which are core components of self-control" (p. 43). From this perspective, the very high level of literacy in early modern England suggests high levels of self-discipline.

5.4.2. Optimism

Cultural historians have long noted that the early modern English people became unexpectedly optimistic. In his famous study on the decline of magic, Keith Thomas noted that:

> In many different spheres of life the period saw the emergence of a new faith in the potentialities of human initiative. … The change was less a matter of positive technical progress than of an expectation of greater progress in the future. … It marked a break with the characteristic medieval attitude of contemplative resignation. (Thomas 1971)

What was striking, noted Thomas, is that this optimism in the power of technical progress could not be based on actual evidence. "It is often said that witch beliefs are a consequence of inadequate medical technique. But in England such beliefs declined before medical therapy had made much of an advance" (Thomas 1971, p. 1221). In the same way, the popularity of the work of Francis Bacon in the seventeenth century, that is, before the great wave of technical progress, attests that the English were very receptive toward optimistic ideas (Mokyr 2016). As Mokyr (2016) notes, they no longer subscribed any more to "the Ecclesiastes view of history," which holds that long-term change is impossible, because "there is nothing new under the sun" (p. 19). (See also Wootton [2015] on the contrast with late Renaissance scholars.) Although words such as "innovation" and "novelty" often used to have negative connotations, these same words started to look more positive, and the emotional attachment to traditional ways of doing things progressively decreased (McCloskey 2016a, p. 94). And again, the phenomenon seems to have been exacerbated in England. For example, Voltaire, in his *Letter on the English*, reports that science is much more popular in England than on the Continent. "The message of Voltaire's book was that England had a distinctive scientific culture: what was true of an educated Englishman in 1733 would not be true of a Frenchman, an Italian, a German or even a Dutchman" (Wootton 2015, p. 35). The national funerals of Newton attest that science and the pursuit of novel knowledge had achieved a very high status in eighteenth-century England.

5.4.3. Materialism and conscientiousness

More indirect and qualitative evidence of a change in reward orientation can be found in the historical literature. For example, the popular success of etiquette books such as Erasmus's *De civilitate morum puerilium*, studied by Elias (1982), suggests a growing interest in self-discipline. Similarly, the spread of Puritan movements in England and northwestern Europe shows that a substantial part of the population in these areas favored higher levels of discipline with regard to alcohol, sex, and violence. The first large-scale campaigns aimed at reducing excessive alcohol consumption were launched during the same period (Eisner 2014), and some evidence suggests that alcohol consumption did in fact decrease in the seventeenth and eighteenth centuries (Martin 2009). Finally, the views of the English on work changed during the early modern period. Work started to be valued for itself (i.e., for its intrinsic value), and not for what it produced (i.e., extrinsic value) (McCloskey 2016a). Concomitantly, economic historians observed an increase in working days over the year (Humphries & Weisdorf 2016; Voth 2000) and a reduction in people's leisure time, a phenomenon that economic historian Jan de Vries famously called the "industrious revolution" (De Vries 2008). It is usually assumed that this increase in the length of the working year resulted from a desire to buy more goods, but it could also be the product of increased motivation to work and self-discipline, in line with the concomitant rise of investment in education and health.

6. Discussion

6.1. The bourgeois values, the industrial enlightenment, and Protestant ethics

The LHT approach presented here converges with a number of recent studies emphasizing the importance of noneconomic mechanisms in economic history (Clark 2007; McCloskey 2006; 2010; 2016a; Mokyr 2009b; 2016), as well as older work, such as Weber's influential thesis that Protestant ethics favored the emergence of capitalism. The approach taken in this article was in fact very much inspired by these works. For example, as demonstrated in section 5, on the behavioral constellation of affluence, there is a strong convergence between LHT and the theory of the "bourgeois virtues" defended by Deirdre McCloskey (2006). The "virtues" McCloskey describes – temperance, honesty, integrity, trustworthiness, hope, and love – are part of the "slow strategy," or "behavioral constellation of affluence," predicted by LHT. Individuals born into affluence are more apt to trust (Petersen & Aarøe 2015), less likely to take revenge (McCullough et al. 2013), have a larger social circle (Nettle et al. 2011), are less materialistic (Carver et al. 2014), have more self-control (Duckworth et al. 2013), are less sexually promiscuous (Schmitt 2008), form longer-lasting bonds (Simpson et al. 2011), and so on. In other words, they are bourgeois in McCloskey's sense.

In her work, McCloskey credits a set of key events in European history (the four "R's": Reformation, Revolt, Revolution, and Reading) as the ultimate source of the emergence of the bourgeois virtues. But the reason for this series of events remains elusive. Why did northwestern Europe in particular experience such a lucky alignment of the stars? What made reading, religious reformation, and political revolution so appealing to northwestern Europeans? Why at this time and not before? Why there and not somewhere else before? LHT suggests that what made tolerance, democracy, education, and free trade so much more successful than in the earlier modern periods could be that in eighteenth-century Britain, hundreds of thousands of people were ready for such ideas. They were future-oriented enough, cooperative enough, and trusting enough to find these ideas cognitively appealing, just as two millennia earlier, the increasing living standards of the Greeks and the Romans led people to embrace new ethical ideals based on temperance, patience, sexual restraint, and cosmopolitanism (Baumard & Chevallier 2015; Baumard et al. 2015). Thus, LHT could provide a missing link in the Bourgeois Virtues theory: It may explain why this particular set of values ("slow" behaviors) became popular at this particular time (early modern period) and at this particular place (northwestern Europe) in history (see Fig. 7).

Similarly, the "behavioral constellation of affluence" could contribute to an explanation for the cultural evolution described by Mokyr in early modern England, and more generally in Western Europe (see Fig. 6). In *A Culture of Growth*, Mokyr (2016) suggests that the European "République des lettres" formed a marketplace where ideas were in competition with each other. It is certainly true that the Europe of this time was unique in its pluralism and that this competition between ideas helped the best scientific ideas to triumph eventually. But why were so many people willing to participate in the Republic of Letters in the eighteenth century and not earlier? It is striking that, in the period when Bacon was writing (early seventeenth century), there was not yet any evidence that science and technology could make the world a better place. The scientific revolution had just begun, and it would take another century for the Industrial Revolution to take off (in 1704, one of Jonathan Swift's "Ancients" remarks devastatingly that "if one may judge of the great genius or inventions of the Moderns by what they have produced, you will hardly have countenance to bear you out" (Swift 1704/2018, pp. 185–86, cited in Mokyr 2016).

Why were Europeans persuaded by optimistic, but still unproven, ideas? Why was the Baconian program so appealing, and why was it so appealing in England in the eighteenth century? The current success of antivaccine beliefs, climate change skepticism, and conspiracy theories suggests that open competition does not guarantee the triumph of truth. Cognitive approaches to cultural evolution have shown that cultural evolution is constrained by the architecture of the mind (Boyer 2001; Sperber 1996). For example, people tend to pay more attention to rumors or legends containing information about threats (Blaine & Boyer 2018; Fessler et al. 2014). There is nothing inherently appealing in Bacon's optimism: Pessimism could very well have triumphed, as it did everywhere else in earlier periods (see, e.g., Wootton 2015 on the pessimism of medieval scholars).

From this cognitive perspective, the popular success of the Republic of Letters across Europe may be partly the result of increasing optimism in the European population, and in the English population in particular (see Fig. 7). LHT contributes to explaining the success of cultural entrepreneurs such as Bacon and the very existence of a "marketplace for ideas" in early modern Europe. To summarize, the psychological shift toward innovation, optimism, and non-conformism produced by improving living standards likely rendered the Republic of Letters, and Enlightenment ideas, more cognitively attractive. In other words, when Bacon published his work advocating for more experimental research, European elites were ready for such a change.

LHT is also compatible with Weber's famous observation that the ethics of Puritanism favored the emergence of modern capitalism. As we saw in section 5, there is indeed a very visible association between economic growth and a certain form of religion, advocating self-discipline, hard work, trust in others, and long-term investment in education, and it is very tempting to infer from this association that Protestantism contributed to the economic dynamism of the Protestant countries. But LHT suggests that the relationship between religion and economic growth is probably the opposite of Weber's proposition. From an LHT perspective, Protestantism should be a consequence of economic growth, rather than its cause. On this account, it is because living standards and human development were increasing in Britain, Germany, or Scandinavia in the sixteenth century that Protestant ideas became popular in these countries. Protestant leaders' insistence on self-discipline and education resonated with people's growing preference for future-oriented behaviors. In the same way, the economic boom in Western Europe during the central Middle Ages (1000–1300) had an impact on the preferences of the urban upper middle class and led to the emergence of ascetic movements advocating for greater self-discipline and charity, both within the Church (e.g., Franciscans, Dominicans) and outside it (Beguins, Waldesians, Cathars; Little 1983).

Finally, there is a clear convergence between the LHT approach and Gregory Clark's approach in *A Farewell to Alms* (Clark 2007), in the sense that both approaches argue that there was a transformation of individual preferences before the onset of the Industrial Revolution (see, in particular, chapter 9, "The Emergence of Modern Man," in Clark 2007). In addition, the LHT approach advocated here and Clark's selectionist theory both rely on the tools of evolutionary biology (see also Galor & Moav 2002 for a selectionist approach to economic growth). However, the mechanisms put forward by the two theories are rather different: For the selectionist approach, modern preferences were genetically selected in Europe during the medieval and modern periods, whereas in the life history approach, modern preferences are the product of universal mechanisms that modulate individual behaviors in response to environmental changes. The two theories make different predictions because the two mechanisms (natural selection and adaptive plasticity) do not work at the same time scale: Favorable alleles need several centuries (several dozen generations) to invade a human population while adaptive plasticity mechanisms allow behaviors to change within a single generation (sometimes in a very short time span). The selectionist approach thus predicts that it will take some time for non-English and non-European populations to exhibit modern behaviors. By contrast, Life History Theory predicts that the "culture of innovation" will spread very quickly. As soon as a society reaches a certain level of affluence, individuals should exhibit the same level of innovative behaviors as the English did, which is what happened very quickly in continental Europe (France, Germany, Scandinavia), the United States, and Japan.

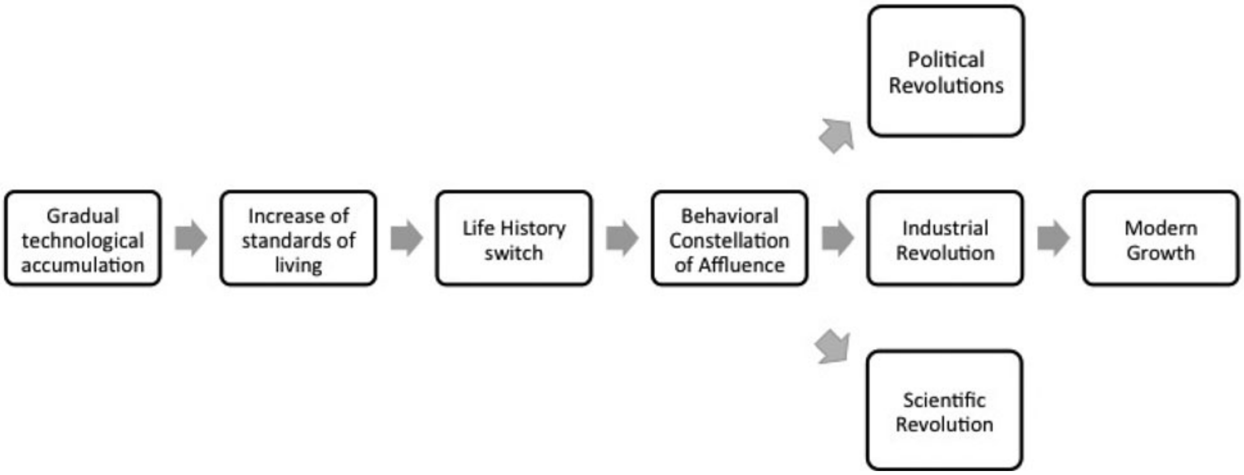

Figure 7. The Bourgeois Revaluation and the Republic of Letters in an LHT perspective. As indicated in the figure, increasing political liberalism and scientific advances may also have contributed to the acceleration of growth (see Acemoglu & Robinson 2012; McCloskey 2016a; Mokyr 2016).

6.2. Endogenous growth theories and long-run development

The approach taken here is agnostic on why England was the wealthiest society in the eighteenth century. It is certainly the case that England benefited from the heavy plow revolution (Andersen et al. 2016), specialization in new draperies (Allen 2009b), and the explosion of Atlantic trade (Acemoglu et al. 2005), to name but a few contingent and temporary advantages. But if England had not existed, the same acceleration of innovation would probably have occurred anyway, albeit probably a bit later. Living standards were already improving in other countries, such as France, Germany, and the United States. The most productive areas of the Western hemisphere would probably have sooner or later achieved eighteenth-century-English living standards and experienced a similar acceleration of innovation. A similar observation can be made for China and Japan: Many indicators (literacy, urbanization, etc.) suggest improving standards of living in these countries on the eve of the Industrial Revolution (Clark 2007). If Europe had not existed, the gradual rise in living standards as a result of technological progress would eventually have triggered an industrial revolution, probably first in Japan and then in Korea or in China (Baten & Sohn 2013).

In this perspective, the LHT approach is very much in agreement with endogenous growth theories, and in particular with unified growth theory (Galor 2011), in which growth and technological progress are endogenous and do not require any external input (political revolution, technological breakthroughs, etc.). LHT provides a plausible mechanism by which economic prosperity can be self-sustaining: Technological progress leads to higher standards of living, which lead to more future-oriented preferences, in turn increasing technological progress, and so on. However, in contrast with unified growth theory, here the main mechanism is not rising *demand* for human capital triggered by rising technological levels, but simply rising *levels* of human, physical, and social capital allowing individuals to increase their investments in technological progress.

Capital is thus central in LHT. A certain level of human, social, and technological capital is indeed required to develop the kind of preferences that are conducive to learning and mastering the new innovation. This idea fits well with the growing body of work on the long-run determinants of wealth: Because capital accumulates over time, the early starters in economic development still enjoy some advantages today, and despite institutional reforms and technological transfers, most developing countries still have a hard time catching up with the most advanced countries (Abramson & Boix 2014; Chanda & Putterman 2007; Comin et al. 2010; Diamond 2011; Olsson & Hibbs 2005). From this long-term perspective, there is actually nothing special about the Industrial Revolution. The rate of innovation has been increasing exponentially since the Neolithic, and the Industrial Revolution is just the moment at which the exponential nature of the acceleration became undeniable. What LHT brings to this literature is that this acceleration is partly a result of psychological changes in individual goals.

6.3. Testing the theory

6.3.1. Were English people really richer and slower?

One way to falsify the theory presented here would be to show that northwestern Europe, and England in particular, were not so wealthy or not so slow (see, e.g., Allen 2017a; Stephenson 2017 about whether English wages were lower or higher than in other countries). Also, I have taken for granted that English industrial success reflected the greater innovativeness of the English population. However, it could be that the English were no more innovative than other Europeans, but only better at tweaking and marketing existing inventions (thanks, e.g., to better institutions). Therefore, another way to falsify the theory would be to test whether English people were indeed more innovative, using, for example, large biographical databases such as Freebase and Wikipedia (Gergaud et al. 2017; Serafinelli & Tabellini 2017), comparing the number of innovating individuals (scientists, artists, engineers, inventors) across European countries.

6.3.2. Is the association between affluence and innovation really causal?

Even if it is confirmed that England was indeed ahead both in terms of living standards and innovativeness, the historical

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evidence presented here remains correlational. Is it possible to test the causal role of affluence in shifting attitudes? To do so, we would need (1) an external shock on individual income and (2) some measures of psychological variables in the *longue durée*. Along with others, I have studied the effect of economic growth on individual psychology during the Middle Ages (Baumard et al. 2018). We used the introduction of the heavy plow as an instrument for economic growth to identify the causal impact of economic growth. Following Andersen et al. (2016), our instrument exploits two sources of variation: variation over time arising from the adoption of the heavy plow on the one hand, and cross-sectional variation arising from differences in regional suitability for adopting the heavy plow on the other hand. We focused on two behaviors – asceticism and romantic love – that can be quantified over the long term through relatively homogenous sources (the biographies of the saints for asceticism, and the topics of narrative fictions for romantic love). Our results show that economic growth measured through higher population density indeed caused an increase in behaviors associated with a slow life history (i.e., both more ascetic and more romantic behaviors). Future research should use similar instruments to test and quantify the impact of affluence during the early modern period.

6.3.3. Are there more parsimonious explanations of changes in attitudes?

One final way to falsify the theory would be to show that there is no need for psychological changes to explain increasing levels of innovativeness. In a purely rational choice approach or the critical revision of such approach (à la Kahneman and Tversky, for example), individuals are able to compute the risks of their investments, and are aware that these risks are greater when their resources are scarce or when their time horizon is short. Thus, in principle, a large part of the Industrial Revolution could be explained without resorting to LHT: English people were more innovative not because their preferences had changed, but simply because they had an unprecedented amount of resources. In this view, Wedgwood, for example, was able to improve ceramic mixtures and glazes only because, unlike his predecessors, he had the time and money to perform his famous 5,000 experiments.

How can we disentangle the LHT approach from the more standard rational choice approach? A life-history switch from a fast to a slow strategy makes a range of predictions not just about decision-making, but also about human psychology in general. For example, LHT predicts that the rate of innovation in England should have been higher in general, not only in industries where it was economically profitable, but also in the sciences and the arts, where the benefits were not so great. Changes in attitudes should also reflect in works of fiction. In *Bourgeois Equality*, McCloskey (2016a) notes that whereas ancient narratives such as the *Odyssey* and the *Aeneid* tend to focus on extrinsic rewards such as fame, money, and marriage (see sect. 3.3), early modern English novels such as *Robinson Crusoe* (1719) show an intrinsic interest in planning, deliberation, and technical details, that is, on the kind of information that individuals pursuing a long-term strategy would like.

LHT also predicts changes outside the economic domain – in love, for example. According to LHT, individuals growing up in affluent environments are more motivated by long-term pair-bonding and show stronger attachment to their spouses (Chisholm et al. 2005; Del Giudice 2009; Quinlan 2003; Simpson et al. 2011). Thus, LHT predicts that higher levels of innovativeness should be associated with greater romantic attachment, which is what is observed in the Roman period and the medieval period, as well as in the early modern period with an increase of romantic works (e.g., *Tristan and Iseult*) during periods of affluence (Baumard et al. 2018). Growing empathy toward others, even without economic motives or personal gains such as in the case of slavery, is also predicted by LHT, but much less so by rational choice theory. Our work confirms this prediction, showing that facial cues associated with trust increased over the period of 1500–1900 in English portraits and that this increase was best predicted by the rise of life expectancy and GDP per capita (Safra et al. 2019).

Finally, LHT predicts attitude changes much less fine-grained than those that would result from standard behavioral mechanisms attuned to day-to-day changes in circumstances. For example, LHT studies have reported that many variables, such as mating, time discounting, and trust, are partly calibrated during childhood or even in utero, and that later changes in the environment cannot offset these early calibrations. Overall, LHT predicts the emergence not just of new behaviors in response to new incentives, but of a whole new mentality.

6.4. Beyond the industrial revolution: Explaining cultural revolutions in history

This article focuses on the Industrial Revolution, but in principle, LHT provides a framework not just of the origins of the Industrial Revolution but also, potentially, of the entire "civilizing process." From an evolutionary point of view, the "civilizing process" might indeed be the "constellation of affluence" expressed at a larger scale: With growing affluence, people's psychologies changed, which allowed for more innovation and higher economic growth, but also for higher levels of social trust, explaining the strong association between affluence and democracy (Boix & Stokes 2003; Inglehart & Welzel 2005; Przeworski et al. 1995). In his pioneering work *The Silent Revolution* (1977), Ronald Inglehart demonstrated how the cohorts born after World War II and raised during a period of fast economic growth were much less materialistic and much more tolerant than the previous generation, in line with the LHT framework. The same logic may be at play today, with the slow and yet massive transformation of modern societies in the direction of greater respect for human rights and greater inclusion of females as well as sexual and ethnic minorities (Fariss 2014; Norris & Inglehart 2011; Pinker 2018).

To conclude, Life History Theory has the potential to explain slow and silent changes in history: changes that occur without any apparent modification of the political, religious, or institutional environment. This tool also has the potential to explain how long-term material changes can have dramatic effects on human societies. With the help of Life History Theory, we are now in a position to better understand how living conditions can modify individual preferences and eventually change the course of history.

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Open Peer Commentary

Explaining historical change in terms of LHT: A pluralistic causal framework is needed

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Abstract

Baumard suggests that the advent, through phenotypic plasticity mechanisms, of future-oriented preferences and creative mindsets in eighteenth-century Great Britain explains the wave of innovations that drove the British Industrial Revolution. We argue that, although this approach is promising, Baumard's model would benefit from being supplemented by demographic, economic, and sociological explanations independent of Life History Theory (LHT).

Baumard proposes that the advent of future-oriented preferences and creative mindsets in eighteenth-century Great Britain may be explained as genetically driven cognitive adjustments to environmental change. This set of preferences would then have caused the cascade of technological innovations characteristic of the Industrial Revolution.

We view Baumard's proposal as a bold and original contribution for at least two reasons. First, it convincingly suggests that a significant part of cultural stability within a given historical time period (i.e., eighteenth- and nineteenth-century England) may result from the influence of low-level "cognitive attractors" (viz., "slow" preferences and intuitions) on individuals' aspirations and conduct (Sperber 1996; Sperber & Hirschfeld 2004). This attractionist causal framework is explicitly presented as an alternative to institutionalist approaches. But it also departs from models of cultural evolution focused on the influence of reflexive, culturally transmitted prescriptions (e.g., to cooperate or to save one's money) that often suffer from the limitation of overestimating the motivational power of reflexive beliefs on individual conducts, without first asking the question of which underlying psychological substrate those norms require to enjoy cultural success (Norenzayan et al. 2016; Weber 2002).

Second, Baumard's framework is to be praised for exploring the idea that the jurisdiction of the evolutionary sciences is *not* limited to explaining fixed and stable traits, but also traits that vary between populations and over time. Changing ancestral ecologies and the adaptive trade-off between specialization and flexibility often selected for an array of potential behavioral reactions. Commitment to the existence of a *universal* biological predisposition is compatible with the recognition of it displaying important local *variability*. Conversely, cultural variability on a trait is *not* an argument against it having a potentially strong genetic basis. Emphasizing these points seems particularly important because of the frequent and unfortunate tendency to pit purely "biological" explanations against purely "cultural" ones, as if they were mutually exclusive.

Now, what remains unclear to us is the exact status Baumard attributes to phenotypic plasticity mechanisms within the wider causal account of the Industrial Revolution. Should the generalization of a "slower" mindset in eighteenth-century England be considered a necessary cause of the revolution, a sufficient cause, or neither? Baumard's framework does not acknowledge any explanation aside from LHT, which suggests that he intends genetically driven change in preferences in response to environmental shift to be explanatorily sufficient. The issue, however, is that Holland was in the eighteenth century richer and more urbanized than England (Baumard sects. 4.2 and 4.3; Broadberry et al. 2015). If a "psychology of affluence" (sect. 3) developed in Great Britain, one would also expect it to have developed in Holland and to have brought about similar consequences. Yet, it was in Great Britain that the Industrial Revolution took off. Therefore, phenotypic plasticity alone cannot account for the divergent development of these countries. We surmise that Baumard's narrative would benefit from being supplemented by more classical demographic, sociological, and economic considerations. We illustrate the importance of such factors by taking the example of population size, which we consider to be crucial.

Research based on both theoretical models and historical studies (Henrich 2004; Kremer 1993) has shown that technological progress increases as a linear function of population size. This stems from at least two reasons. First, *ceteris paribus,* the larger the population, the greater is the likelihood of inventions being made. Second, technology and knowledge are nonrivalrous: A given innovation can be enjoyed by many consumers simultaneously without any additional cost. Thus, the average amount of goods and services enjoyed by each consumer increases in direct proportion to the total number of inventors and their output (Kremer 1993). Third, culture being cumulative, innovation is fueled by people's tendency to imitate and get inspiration from the most successful inventions available (Henrich 2004). Consequently, a larger population increases the probability of emergence of exceptionally creative individuals, whose innovations will be enjoyed, imitated, and improved by the rest of the population.

Adding these demographic considerations to Baumard's model is all the more important because their force is magnified by a country's wealth and level of education. As Squicciarini and Voigtländer (2015) stressed, the upper class acquired a special importance for economic development at the onset of the Industrial Revolution because of its members' high level of knowledge and wealth. Independent of LHT mechanisms, these assets enabled the upper class to afford technical education, to dedicate free time to technological exploration, and to stay constantly informed of the latest innovations.

Great Britain, at the dawn of the Industrial Revolution, combined two factors: a high level of economic prosperity *and* a large population. As Baumard showed (sect. 4.2), other populous European countries, such as France and Germany, were much poorer. Holland, one of the only other countries that rivaled England's prosperity (Broadberry et al. 2015), had only 2 million people in contrast to Britain's 6 million (or 9 million, if one includes Ireland; Broadberry et al. 2015; Livi Bacci 2000). The conjunction of high prosperity and demography would have enabled the British economy to benefit from a pool of innovators both exceptionally large and affluent.

We do not want to suggest that the size of such alternative mechanisms would have been massive. What we want to argue is that they should be taken into account as plausible and parsimonious complements to LHT. There is no doubt that traditional historical research has neglected evolved psychological dispositions, that cognitive attraction accounts are a major achievement of the naturalistic social sciences, and that LHT is an interesting tool for explaining diachronic and synchronic variation. But Baumard, in turn, seems to be minimizing the importance of demographic and sociological factors. Pendular oscillations between sharply contrasted explanatory models are recurrent throughout the history of science. However, theoretical accuracy culminates in interdisciplinary syntheses that manage to do full justice to the causal complexity of history. Baumard's theory provides the basis for an even more exact and inclusive model of the origins of the Industrial Revolution that would eschew the temptation of causal reductionism.

Psychology and the economics of invention

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Abstract

Invention is an investment in which the costs of the Research and Development (R&D) project balance future returns. Those returns depend on objective factors like wage and capital costs but also on subjective factors because they are future projections. The more optimistic the inventor, the higher are the projected returns. Baumard uses Life History Theory (LHT) to relate optimism to the affluence of inventors and their societies.

The problem is to explain the Industrial Revolution and the subsequent period of modern economic growth. The driver of economic growth is technical progress, as Baumard recognizes. To explain the Industrial Revolution, we must explain why there was an upswing in technical progress in England after the middle of the eighteenth century.

Many explanations have been offered. I have argued that England's empire led to a trade boom that created a high wage, cheap energy economy that made it profitable to invent machines that economized on expensive labour by using more capital and energy (Allen 2009b, 2017b). England's high wage economy increased the *demand* for labour saving technology that increased output per worker and income per head. Other answers include the Scientific Revolution and the creation of a popular scientific culture (Mokyr 2002; 2016), England's political institutions (Acemoglu & Robinson 2012), and a rational and enterprising culture (Clark 2007; McCloskey 2006). More scientific knowledge, more secure property rights, and more entrepreneurship increased the capacity to respond to any given set of incentives and, thus, the *supply* of inventions.

Baumard adds another supply side explanation to the mix based on evolutionary biology. Britain's high wage economy not only increased the demand for inventions, but it increased the supply of invention, as well. The link is Life History Theory, which implies that a more affluent environment makes animals and people more future oriented. Baumard claims that affluent humans are more optimistic about the future and have a lower discount rate. England was exceptionally prosperous at the outset of the Industrial Revolution, and that prosperity led to the upsurge in invention through these channels.

I see invention as essentially an economic challenge: The aim was to develop a product or a process that makes money. The famous textile machines of the Industrial Revolution were designed to cut labour costs. The engineering ideas were simple. The problem was to convert them into devices that could be operated reliably by low-skilled workers. It was the same story with Newcomen's steam engine: even though the initial idea stemmed from science, twelve years of work and expense were needed to convert the science into a working engine.

The decision to invent was, therefore, an investment decision. The costs of the development project had to be more than offset by the profits created by the invention once it came into use. When the decision was taken, this was not known with certainty. It was a forecast. Objective factors were involved: If the aim of the project was to create a machine that saved labour by substituting capital for it, then the return was higher, the higher was the wage. This is the demand side of the question. But the future values were not known with any certainty. They were projections, and the more optimistic were the inventors, the higher were the projected future benefits, whatever the objective circumstances.

This is where LHT makes a contribution, for it implies (in Baumard's hands) that people in eighteenth-century Britain were more optimistic than they were in other places or than they had been at earlier times because wages and other incomes were higher in England in the 1700s.

Although Baumard offers some evidence in favour of the view that people were more optimistic and forward looking in eighteenth-century Britain, more systematic work needs to be done to support the theory. First, it is not clear how the theory could be distinguished statistically from alternative explanations. Economists – and people in general – have long known that preferences vary with income: poor people spend much of their income on food and better off people spend little. When people get richer, they have more resources for luxuries including R&D, and there is less risk that they will starve if the project goes wrong. Baumard claims that "What LHT does is explain why human needs are prioritized as they are." LHT is a theory that claims preferences shift when people are more affluent. Does LHT add anything to common sense explanations? How could we identify a preference shift at the societal level with data we could imagine collecting?

Second, there are simple comparative questions that a historican would ask. Eighteenth-century England was not alone in having a high income. The Netherlands was the richest economy of the day, but the Industrial Revolution passed it by. Why? Moreover, there were other high-wage economies that were not particularly inventive like Europe after the Black Death. Why not? Furthermore, there were many high-income groups in earlier societies that did not show the virtues Baumard emphasizes – the medieval aristocracy, for example. Perhaps more is involved in developing modern values than high incomes?

Third, how did optimistic views evolve historically? When the Royal Society was founded in 1662, it aimed not only to advance science through experimentation, but also to apply the results of that science to technical problems. Indeed, Robert Boyle (1671, Essay 4, pp. 10, 20) argued that natural philosophers could invent better clocks, better dyes, and, especially, labour-saving machines. Boyle was constructing a narrative of progress that highlighted the possibilities of successful invention. Did this narrative and others like it make people more optimistic? Did the invention of new technology feed the narrative, increasing optimism further? Did this lead to an ascending spiral of invention and optimism?

Baumard has made an important contribution in highlighting the role of optimism in R&D decision making. I look forward to more research on the LHT approach and the ways in which it interfaces with other historical approaches and data.

What came first, the chicken or the egg?

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Abstract

Current empirical evidence does not seem to confirm that an improvement in living conditions is the cause of the shift in the human mindset toward innovation and long-term risky investment. However, it may well be one of the conditions for greater tolerance of income inequality in exchange for a steady increase in average income.

Baumard proposes a neurocognitive model, inspired by the results of the Life History Theory (LHT), to explain the strong acceleration of innovation dynamics – considered as the engine of modern economic growth – in England and then in continental Europe since the Industrial Revolution. Baumard explains this acceleration by a change in neurocognitive processes of humans, that is, their preferences, resulting from an improvement in people's living conditions.

The explanations of the Industrial Revolution can be classified according to three approaches: the incentive-based approach, the idealistic approach, and the hybrid approach (Clark 2012). Baumard's model belongs to the latter approach whereby the Industrial Revolution has its roots in a particular set of values dependent on materialistic or demographic forces (e.g., Clark 2007; de Vries 2008; van Zanden 2008). His model can be related to the idealistic explanations of the Industrial Revolution proposed by Mokyr (2016) and Wootton (2015; 2017; 2018), where cultural change takes place within the elite, which, through its innovations and investments, is transforming technologically and economically society as a whole. Their explanations are therefore top-down and do not depend on the average standard of living of the population. Baumard admits that most innovators are rich and literate individuals but considers that the improvement of living conditions for the average individual has allowed this elite to be more numerous and the rest of the population to be more tolerant and optimistic in the future. Baumard's top-down explanation implies a greater penetration of neurocognitive and cultural change in society.

We agree with the thesis that a change in the mindset of the English and European elites is a determining cause of the Industrial Revolution. The crucial question is what caused this change in mindset. The explanation proposed by Baumard is not specific to England or Europe but is universal. Once living conditions are sufficiently high, the mindset changes. However, the causal chain of his model can only be accepted …

If the living conditions actually improved in pre-industrial England and Europe, as well as in all countries that have experienced the Industrial Revolution

Whereas recent studies confirm the existence of some growth of GDP per capita in both England and The Netherlands before the Industrial Revolution – an evolution labelled as the "Little Divergence" by early modernists – the empirical literature provides less support for significant economic expansion in the rest of Europe during the pre-industrial period. In addition, the causal chain of Baumard's model implies that the early improvement of living conditions in England must be translated into European and global leadership in innovations to explain English leadership in the takeoff of economic growth. The empirical literature does not seem to confirm the English domination in inventions at that time, particularly macroinventions (e.g., Meisenzahl & Mokyr 2012; Mokyr 1999). For example, Mokyr (1999, p. 24) notes:

> Britain seems to have no particular advantage in generating macroinventions; a large number of them were generated overseas, especially in France. Steampower and cotton technology were British inventions, but many of the other [macroinventions] were imported: Jacquard looms,

chlorine bleaching, the Leblanc soda-making process, food canning, the Robert continuous paper-making process, gaslighting, mechanical flaxspinning.

If the relative prosperity of pre-industrial England reached a level never reached by a country before to explain an event, the Industrial Revolution, which had no precedent

Although it is now widely accepted that England experienced a growth of GDP per capita during the pre-industrial period (1650–1700), England's unprecedented wealth before the Industrial Revolution is not well established in the literature. Recent estimates by Maddison (2007) and Broadberry et al. (2015) show that The Netherlands was seemingly the most affluent country before the onset of the Great Divergence. Goldstone (2015), moreover, contends that the episode of growth observed in England during the pre-industrial period, especially between 1650 and 1700, was not very different from the earlier pre-modern efflorescences like those of Song China or Renaissance Italy, with impressive per capita growth that then shows a tendency to peter out. Why did the Industrial Revolution occur in eighteenth-century England, and not earlier in Song China or Renaissance Italy?

If reverse causality can be dismissed

Baumard's causal chain can be completely reversed by assuming, for example, that the invention of printing has made it possible to disseminate knowledge at a much lower cost than before, allowing the emergence of a common culture and a broader educated elite (Mokyr 2016; Wootton 2015; 2017; 2018). This culture, more open to science, creativity, and innovation, would have enabled this elite to aspire to change by investing in commercial and technological entrepreneurship rather than war or land ownership. The improvement of living conditions is not a necessary prerequisite but is the consequence of the investments and innovations of the elite. Economic growth accelerates when investment returns reach the macroeconomic scale.

In light of the empirical information currently available, it is very difficult to conclude where the causal chain starts. Perhaps there is even a two-way causal relationship between a change in the mindset and living conditions. In fact, Mokyr and Wootton's elite-based and Baumard's average man based-explanations are not incompatible. Better living conditions of the average man in pre-industrial society pacifies social relations allowing respect for property rights and, in particular, the ownership of future earnings from long-term investments and innovations. North (1990) makes respect for property rights one of the institutional determinants of economic development. Baumard's thesis helps to explain the advent of and respect for this institutional environment. Although the acceleration of economic growth has been accompanied by rising inequality and social protest, the dynamics of innovation and economic growth have never been stopped, let alone reversed. Baumard's thesis would be convincing if it can be shown that the enrichment of an elite, even a larger one, could percolate into the whole society thanks to the greater patience and tolerance of the rest of the population resulting from the affluent mindset. For the moment, this chicken-and-egg problem with the source of the Industrial Revolution has not been solved.

What motivated the Industrial Revolution: England's libertarian culture or affluence *per se*?

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Abstract

What impelled the Industrial Revolution's spectacular economic growth? Life History Theory, Baumard argues, explains how England's world-supreme affluence psychologically fostered innovation; moreover, wherever similar affluence abounds, a "civilizing process" bringing enlightenment and democracy is apt to evolve. Baumard insightfully analyzes a "constellation of affluence" but proffers somewhat whiggish history given England's prior and unique proto-capitalist culture of economic liberty and individualism.

Using evolutionary Life History Theory, Baumard claims England's superior seventeenth-century living standards psychologically fostered spiraling wealth via sustained innovation grounded in less discounting and materialism, greater optimism and trust. Although behavior of elites and a growing middle class provides support, these factors are less evident for propertyless workers compelled by emerging markets to sell their persons (labor) and traditional livelihood (land) as alienable commodities. Ensuing variety of choice and competition in selling and buying once inalienable parts of community life favored psycho-political notions of rational self-interest, criticism, experimentation and creative destruction, free-flow information, science, individual rights, liberal democracy, and society conceived as reciprocal, utilitarian relationships (economic, juridical, political) freely contracted between autonomous agents (Macpherson 1962; Mill 1956/1859). Performance-oriented ideals of trust based on competence, reliability, and verifiability (Mayer et al. 1995) replaced communitarian ideals rooted in devotion, shared fate, and emotional attachment.

Unique historical factors operated: England's highly individualized, impartible property regime, a twelfth-century world novelty (Maine 2010/1875); general adherence to a thirteenth-century Church prohibition against cousin marriage to fourth degree (including through marriage [Worby 2010]), which undermined kin-based society while encouraging wider socioeconomic relationships; England's singular proto-capitalist society by at least the twelfth to thirteenth centuries, contrary to presumptions by Marx (1867/1992), Weber (1923/1961), and Polanyi (1944/2001) that capitalism emerged from English "peasant society" (e.g., wills allowing landholders to disinherit any kin, late marriage for women and spinsters' rights to contract land and labor, geographical mobility of rural families and individuals, hired agricultural labor, monetized markets [Pollock & Maitland 1898/2010; Redfield 1956; Shanin 1971]; sixteenth- to eighteenth-century enclosures of village commons lands, which accelerated privatization, sale, and alienation to large and absentee landowners, facilitating wage labor and urban migration [Thompson 1991]; seventeenth- to eighteenth-century access to vast overseas populations and resources, spurring demand and production (e.g., the spinning jenny increased cotton production demanded by the textile industry, initial engine of an industrial-based world economy [Hobsbawm 1962]).

Evidence that increasing affluence engenders less discounting and materialism, greater trust, and optimism comes mainly from studies of dubious historical relevance: that casino wealth distributed among Native American Cherokee increased cooperation and social trust in a fragmented society (sect. 3.6, para. 1) disregards tight cooperation before near extermination and herding into reservations (Hatley 1995); the claim that "individuals growing up in affluent environments are more motivated by long-term pair bonding and show stronger attachment to their spouses" (sect. 6.3.3) cites as support studies from contemporary Australia, the United States, Canada, Israel, and Italy (with Hungary one study's outlier); and so on.

Aspects of discounting and concern with material interests were sometimes more pronounced, or differently construed in capitalist England versus pre-capitalist societies. Thus, in peasant economies, household heads are only stewards and caretakers of land for subsequent generations, whereas in thirteenth-century England, welfare of future generations could be discounted (so children might require parents to formally contract for care in old age). True, one argument for disinheritance was that an *individual* would "scarcely be found to undertake a great enterprise in his lifetime if … compelled against his will to leave his estate to ignorant and extravagant children" (Bracton 1968/1235, p. 178); however, this relates little to belief in social or spiritual welfare. In seventeenth- to eighteenth-century England, as in the thirteenth to fourteenth centuries, land turnovers were so frequent that "the land market may have been utilized less for creating permanent additions to total acreage than to meet immediate and temporary needs or for quick gain" (DeWindt 1972, p. 543).

Yet, as one sixteenth-century Frenchman noted: "England is so fertile and fruitful, that comparing quantity to quantity, it surmounts all other lands in fruitfulness…. Wherefore they live more spiritually … more apt and fit to discern in doubtful causes of great examination and trial, than are men wholly given to moiling in the ground" (Fortescue 1969/1567, p. 66). But such observation was more appropriate to England's independent farmers (yeomen) and trading class (including lawyers for contracts and inventors of new tools and means of production) than propertyless laborers. Granted, England was Europe's first to implement poor relief (for centuries, Muslim countries had taxed for poor relief); initially, however, this was less for the poor's welfare than to prevent banditry and social unrest by an emerging laboring class, *increasingly numerous and impoverished* relative to the landed gentry and rising commercial class. In this vein, religion for Hobbes (1651, pp. 260–261), which is "above" and "against" reason, should be inculcated in "common-peoples" to provide "security, against the danger that may arrive … from rebellion." Similarly, for Locke (1824/1695, pp. 146–157), "religion suited to vulgar capacities" is "the sure and only course to bring them to obedience and practice."

Eventually, economic growth began to raise wealth and education levels among all classes. In Britain's American colonies, which boasted the world's highest living standard, property-less free laborers and artisans were first promised full political rights if they voted separation from Britain (lacking their support, a previous vote in the Continental Congress failed). But it was lure of greater individual rights and freedoms – of liberty – for which the rebels pledged "our Lives, our Fortunes, and our sacred Honor," not greater wealth. More generally, the "constellation of affluence," including "The Republic of Letters" and liberal democracy, arises not from affluence *per se*; rather, England's (and America's) increasing affluence and liberalism stemmed from a peculiar culture of economic liberty and individualism (Macfarlane 1978). (Even post-Mao China prospers with a political economy more akin to Hobbes's ideal than Marx's.)

According to Haidt (2012), "liberty/oppression" is a universal moral dimension. Actually, individual liberty (versus group desire for freedom from other groups) is primarily an English cultural innovation that promoted individual rights and social mobility, market capitalism, affluence for an expanding middle class (but also mass impoverishment of property-less laborers), and world reach (now challenged partly because of social, economic, and emotional dislocation without a traditional community fallback, resulting from the forced gamble of globalization [Mishra 2017]).

Baumard concludes (sect. 6.4, para. 1): "From an evolutionary point of view, the "civilizing process" might indeed be a "constellation of affluence" expressed at a larger scale … explaining the strong association between affluence and democracy." This is another recent version of Whig history popular in the post-Cold War West (Fukuyama 1992; Pinker 2011b; Wright 1999), characterized by humankind's ostensible progress toward greater Western-like liberalism and enlightenment under presumptive universal evolutionary principles mechanistically applied to human history. (Marxism is a related story with another end game, produced when *shared deprivation induces cooperation*.) Although somewhat a corrective to relativism, the arc of history described glosses over the formative role of particular contingencies and their spiraling context-sensitive effects (Atran 2019; Clauset 2018).

For Hobbes (1651) and Locke (1824/1695), philosophizing in the chaos and aftermath of an English Civil War prompted by royal privilege resisting emerging market forces, individual liberty acting for self-gain was the imagined "state of nature." Domesticated from ruthlessness by social contract (Hobbes's strong sovereign, Locke's representative government of property holders, Jefferson's and Mill's minimalist authority), liberty would create collective affluence. Rising affluence, in turn, would make liberty contagious, despite the undertow from socially unmoored poor. But will rising affluence, by itself, promote liberty's further advance, as Baumard surmises – versus, say, a security state to protect affluence or a selfie degeneration into affluence-seeking identity cults?

Life History Theory and the Industrial Revolution

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Abstract

The most general theory of life history evolution, that of *r* versus *K* selection, implies that innovation in the form of plasticity is more likely to be adaptive under poor rather than good resource conditions, the opposite of how Baumard has it. However, this does focus on benefits rather than costs, and including both allows for greater diversity of outcomes.

Most historians and social scientists undoubtedly would not agree with genetic explanations (whether plastic or not) for events in human history such as the Industrial Revolution. Even if evolution minded, they would more likely point to cultural or sociocultural evolution involving cultural innovation, transmission by social learning through observation or linguistically encoded instructions, and selection, that is, differences in the viability and rates of spread of innovations (e.g., Blute 2010; Boyd & Richerson 1985; Cavalli-Sforza & Feldman 1981). However, Life History Theory (LHT, including adaptive phenotypic plasticity) could be considered in that context, as well.

To the extent that there is a general evolutionary biological general theory of LHT (and it is commonly denied that there is [e.g., Jones et. al. 2014; Reznick et al. 2002; Roff 2002], preferring instead to deal with the relevant pairs of properties individually), the most general theory ever proposed is that of density-dependent selection (MacArthur 1962; MacArthur & Wilson 1967) expressed in the S-shaped logistic function:

$$\frac{dN_t}{dt} = r\left[1 - \frac{N_t}{K}\right]N_t$$

The function relates the growth of a population at time t (the tangent to the curve relating population size to time) to the existing population size (N_t) and two parameters – the intrinsic rate of increase (r) and the carrying capacity of the environment (K). The theory maintains that at low densities relative to resources (or a history of catastrophes in a growing population), selection should act to maximize r by means of rapid growth and development, a small body size, many small offspring in a batch with little invested in each at short interbirth intervals, and a short life cycle. By contrast, at high densities relative to resources (or it should be added with a history of bonanzas in a declining population), selection should act to cope with K by means of longer slower growth and development, a large body size, few large offspring in a batch with a lot invested in each, at long interbirth intervals, and a long life cycle. Think mice versus men. It has been suggested that these are because small organisms, with their disproportionate surface area relative to volume, are adapted to consume (eat and excrete) more and produce more numerous smaller offspring but fewer potential grand offspring from each. On the other hand, the large, with their disproportionate volume relative to surface area, are adapted to digest (break down and build up mechanisms to disperse in time, space, and/or niche) more and produce fewer larger offspring but more potential grand offspring from each (Blute 2016). These r-versus-K properties are all quantity versus quality and current versus future orientation – more or less the reverse of how Baumard has it!

On reflection, however, I was intrigued by his analysis. I think the difference is that evolutionary ecologists commonly deal with the *benefits* of alternative strategies under particular conditions (explicitly or implicitly assuming that costs are equal) with r selection if resources are plentiful and K selection if they are scarce. Baumard, on the other hand, is implicitly paying more attention to *costs*. According to him, the English made the Industrial Revolution because they were affluent and could therefore *afford* to innovate because resources were plentiful. "Innovation" is not a term in LHT but there are two possible interpretations – mutation and plasticity. Because mutations normally occur during DNA replication, they are likely more common in r-selected organisms with their short generation times and many offspring (although not necessarily per capita if somatic mutations are taken into account). Plasticity is normally theoretically associated with uncertainty – uncertainty favouring bet hedging and uncertainty with reliable cues favouring adaptive phenotypic plasticity. However, plasticity is likely more common in K-selected organisms, with their large body size and long life cycle yielding more time and space for morphological, physiological, and behavioural flexibility.

Plasticity is likely to be less beneficial in r-selected organisms and more beneficial in K-selected organisms, enabling the latter to escape from scarcity in time, space, and/or niche but here is the point. Plasticity could conceivably be less costly in r-selected organisms and more costly in K-selected organisms. I would not hazard an opinion on what caused the industrial evolution in eighteenth-century Britain, including whether or not the psychology of individuals was what was important. If so however, it is clear to me that both LHT and Baumard should explicitly include *both* benefits and costs. For example, they should consider the case in which benefits are low and costs high of plasticity under good resource conditions and the case in which benefits are high and costs low under poor resource conditions more like a LHT view. Or, alternatively, consider the case in which benefits and costs of plasticity are low under good resource conditions and high under poor resource conditions, which would at least neutralize the way in which the life history approach seems to contradict Baumard. In any event, I enjoyed reading the article, which raised these issues for me.

The other angle of Maslow's pyramid: How scarce environments trigger low-opportunity-cost innovations

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Abstract

Is it true that innovation occurs only in abundant environments? Baumard defends that increased standards of living are a necessary condition for a change in life history strategy to help understand the Industrial Revolution. Here, we argue that many examples of innovations occur in scarce environments when there is near-zero opportunity cost. We suggest potential psychological pathways to explain this dual-cognitive process.

Baumard suggests that gradual technological accumulation increased standards of living, which in turn may have triggered a change to a slower life history strategy, responsible for accelerating innovations. Here, we assert that Baumard omits the other part of the story: it is not only in affluent and stable environments that innovation can occur. Scarce environments are known to trigger fast life history strategies, which might stimulate problem-based innovations (i.e., when the opportunity cost of the individuals is close to zero). Although this perspective is highlighted by the rich economic and agricultural literature (Garcia & Calantone 2002; Reij & Waters-Bayer 2014), the question of the nature of its psychological pathways still holds. We argue that risk taking, sensation seeking, and local cooperation might be key features in understanding the dynamics of low-opportunity-cost innovations.

Baumard applies a life history framework to resolve the puzzle brought by the so-called "Great Divergence" or "European Miracle." To do so, the author argues that one necessary condition for technological innovation is an "affluent and stable environment" (sect. 1.2, para. 4). Although it is possible that abundant environments may trigger certain types of innovations, so do scarce environments. In a study conducted in Tanzania, students from the Wageningen Agricultural University found that whereas rich farmers innovate as a result of intrinsic reasons (curiousness, entrepreneurship), poor farmers innovate as a result of both extrinsic (monetary rewards, social status change) and intrinsic (creativity, risk-taking, etc.) factors. The poorest farmers had to resort to combining manure, urine, and crop residues to maintain the fertility of their soils. In this study, the authors did not find any resource-innovation correlation. This apparent contradiction comes from (1) poor conceptualization of the term *innovation* (Garcia & Calantone 2002); (2) underestimation of the role of *fast life history strategy* in promoting some types of innovation (Grinblatt & Keloharju 2009; Reji & Waters-Bayer 2014); and (3) ignoring *capital* role in innovation promotion (Verhoeven & van der Kroon 1999).

First, Baumard's focus on technological innovations lacks a clear definition. In a highly influential paper, Garcia and Calantone (2002) argue that there are many types of innovation, some involving riskier behaviors than others. For example, *radical innovation* usually requires discontinuity at both the macro (world/market/industry) and micro (firm/customer, e.g., the World Wide Web) levels. This type of innovation is quite rare and costly, even in rich countries, as it is supposed to make dramatic changes in research/marketing efforts. Discontinuity in one of the two levels (micro/macro), but not both, characterize *really new innovations* (e.g., Sony Walkman, Canon Laserjet, early fax machines). Song and Montoya-Weiss (1998) suggest that *really new innovations* include (1) new technology, (2) significant impact, and (3) being the first of its kind. Other conceptualizations of innovation include *discontinuous* (with 5–10 improvements in performance, 30%–50% reduction in cost, and new unique features); *incremental* (using existing technology to make micro-level shifts); and *imitative* innovations (iterative nature, new at the firm/industry level but not at the market level) levels. Although some innovations occurring during the Industrial Revolution could be classified as radical, many innovations occurring in agriculture could instead be categorized as *really new*. We defend here that *really new innovations* could be explained by both slow or fast life history strategy.

Indeed, as stated by Baumard himself, adverse childhood correlates with sensation seeking and risk taking, one of many characteristics of fast life history strategy. A vast literature associates sensation seeking and risk taking with entrepreneurial, financial, and agricultural innovations (Grinblatt & Keloharju 2009; Reij & Waters-Bayer 2014). In many cases, agricultural innovations in poor countries involve family/local support systems, as new techniques require more labor and resources, which also involve more risks. The latter is actually a good example of how scarce environments may trigger innovations when the opportunity cost is close to zero. As Reij and Waters-Bayer (2014) exemplify:

> Population pressure on a limited natural resource base appears to be an important incentive for innovating and investing in agricultural diversification and intensification. Where farmers have their 'backs against the wall' and few options left, experimentation and innovation find 'fertile ground'. Farmer innovators frequently recount that they were driven by the need to feed their families. For example, when Yacouba Sawadogo was confronted with frequent harvest failures provoked by droughts in the 1970s and many villagers migrated to other regions, he decided to stay on the land of his ancestors and find solutions to this problem. Many similar stories could be told. (p. 83)

Still, although richer and more stable countries might promote high-scale cooperation (e.g., federal taxes), living in a harsh environment may motivate people to collaborate on resolving local issues that need innovative perspectives. A dramatic example comes from neighborhoods with violence-based issues: either the community collaborates to maintain the system (and the economic spinoffs, such as in drug trafficking) or decides to end the supply by cutting off and expulsing the demands (Sampson et al. 1997). Social cohesion among neighbors promotes informal mechanisms that monitor peer groups, prevent truancy, and maintain public order. Again, faced with low-opportunity-cost challenges, individuals sometimes cooperate with one another on behalf of the common good.

In summary, although some innovations seem to be explained by slow life history strategy (individual based, large initial investment, intrinsically motivated), we argue that other innovations may emerge in scarce environments when there is near-zero opportunity cost (problem based, low monetary investment, extrinsically motivated). But how do we explain the high visibility of the former over the latter? One possibility is that to make technological innovation famous, a minimum amount of capital is needed to afford supplies, materials, patents, and marketing. Although such things are difficult in Africa, Reijs and Water-Bayer (2014) still identified more than 1000 innovations during a 2-year research program covering farming innovations. Psychological pathways explaining these innovations include risk taking, impulsivity, and problem-oriented strategies. Further studies are needed to explore the dual-cognitive process that may lead to innovation.

Environmental unpredictability, economic inequality, and dynamic nature of life history before, during, and after the Industrial Revolution

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Abstract

It is emphasized that environmental predictability is another important condition that plays roles in slow strategies that are related to innovation; that economic inequality, except as measured by Gross Domestic Product (GDP) per capita, influences innovation; and that switching global life history from a slow to a fast strategy is a response adopted in response to new challenges during the post-Industrial Revolution period.

The target article concludes that, from an evolutionary life history perspective, the impact of affluent environments on slow life history strategy-relevant psychological traits (e.g., trust, future orientation, and optimism) may partly explain the modern acceleration in technological innovations. However, the article ignores one of two fundamental environmental conditions (i.e., unpredictability) and relies heavily on English GDP per capita as a measure of affluent environment but ignores the economic inequality in England. Last, the article does not explain the developments that followed the Industrial Revolution (e.g., high birth rate and pollution). We argue that life history is dynamic and that this is why English people tended to shift their slow strategies to fast strategies during the post-Industrial Revolution period. In this commentary, we raise three concerns.

First, an individual's life history strategy is shaped by physiological and psychological mechanisms (e.g., attachment; Chen 2018), which frequently involve evaluation of external ecological conditions of the environments and the making of trade-offs in resource allocation as a consequence (Chen 2017). Two fundamental dimensions of environmental risk have been identified as affecting life history outcomes: harshness and unpredictability (Ellis et al. 2009). The target article emphasized only one of the environmental dimensions (i.e., low levels of harshness, or affluence); it ignored predictability. It should be noted that previous work (e.g., Belsky et al. 2012) has demonstrated that environmental predictability and harshness play different roles in life history strategies. Environmental predictability may also lead to the development of psychological traits that are related to innovation. For example, Chen and colleagues (Chen & Kruger 2017; Chen & Qu 2017) found that procrastination, which was related to a high level of future discounting (Chen & Chang 2016), was also indirectly influenced by environmental unpredictability via mediation of life history information processing. Another example is provided by a recent study that showed that adolescents who perceived their environment as predictable were more likely to develop external and internal assets (e.g., constructive use of time, commitment to learning, and positive values; Chen et al. 2019). This evidence suggests that environmental unpredictability may be negatively related to future orientation, whereas environmental predictability may be positively related to future orientation. It is necessary, therefore, to include both harsh and unpredictable environmental conditions in any test of their unique effects on psychological traits, which were discussed in the target article.

Second, the target article argues that environmental affluence increases the absolute number and relative size of "the upper tail of human capital" (sect. 4.5, para. 2) and that upper-class English individuals have played an important role in innovation, making the entire society more open-minded and innovative. This seems to imply that high economic equality (often indexed by the Gini coefficient) in pre-industrial England represents a balanced distribution of social wealth. It should, however, be noted that the GDP per capita can capture environmental affluence, but not economic inequality. Analysis of data from 28 pre-industrial societies (Milanovic et al. 2011) revealed that the inequality indicator was lower in the United Kingdom than in other European countries (e.g., Holland and France) during the same period. Economic inequality has been found to be related to use of fast life history strategies, such as high future discounting (Wilson & Daly 1997) and lack of interpersonal trust (Elgar & Aitken 2010), which are the main psychological traits related to innovation, as discussed in the target article. In addition, it is possible that economic inequality might be a good indicator of both environmental harshness and unpredictability. People in societies with high income inequality may perceive the environment as more harsh than those in societies with less income inequality (Wilkinson & Pickett 2010). Economic inequality may also be related to the unpredictability of future resources (Wilson & Daly 1997), and so, when considering innovation, it is necessary to recognize that economic inequality is one of the important environmental risk factors when it comes to influence on people's life history strategies.

Last, although the target article provides a good discussion of global life history strategy before and during the Industrial Revolution, it seems to ignore life history strategy after the Industrial Revolution. Why did the Industrial Revolution last only about 100 years? How did it affect social environment and individuals' life strategies? Acceleration in technological innovations and the associated economic growth during the post-Industrial Revolution period resulted in environmental pollution (Luckin 2003; Thorsheim 2007), higher rates of birth (Komlos 1990), and an increase in economic inequality (Jackson 2010), which may in turn have led to adoption of fast life history strategies. Thus, life history is dynamic in nature and should be altered in response to environmental changes. The psychological mechanisms that influence life history strategies should take into account cues to environmental conditions. In evolutionary history. the potential benefits of faster strategies in harsh and unpredictable environments may have outweighed the costs, whereas the reverse would be true in more hospitable environments. Environmental pollution and resource scarcity, caused by the higher population density, might favor fast life history strategies. For example, a very recent survey of 9,360 cities in America showed that air pollution predicted crimes (Lu et al. 2018). This study also demonstrated that exposure to air pollution in experimental laboratories induced unethical behaviors (Lu et al. 2018). Criminal and unethical behaviors are considered fast life history strategies (Del Giudice et al. 2015).

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A claim for cognitive history

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Abstract

History is a potential tool for cognitive scientists interested in metacognitive categories like "creativity" and "innovation." As a way of thinking, history suggests alternative accounts of the development of innovation and growth, for example. Life History Theory is one such account, but its roots in the Industrial Revolution make it a problematic tool for telling the history of that period.

Today, most of us think about "innovation" the way Baumard does. We imagine that innovating involves discrete technological developments and eventual economic payoffs. But people did not always think this way. Or more precisely, they did not think *about thinking* this way. Theories of innovation are always theories about cognition, and both have changed over time. Metacognitive categories (e.g., creativity, rigor, evidence, proof) have histories, and these histories interact with what and how it is possible to think in a given moment. So, history and cognitive science have a great deal to learn from one another – just not necessarily on the terms Baumard lays out.

Such a history might start with Baumard's preferred cognitive tool, Life History Theory (LHT). It is not a coincidence that LHT has its roots in the Industrial Age, the very period that Baumard has adapted the theory to explain. Core components of LHT emerged in Malthus's *Essay on the Principle of Population* (1798), a text that also gave rise to the "Malthusian reasoning" that Baumard rejects. Malthus's view of the inevitable competition over scarce resources bore plenty of fruit – including the theory of evolutionary change to which LHT and much else besides are indebted – as did opposition to it (Hale 2014). These ideas about scarcity and surplus are not simply ideas to be refuted by scholars today; they shaped how that refutation is expressed and, indeed, how modern growth was first theorized.

It was Charles Darwin, Malthus's most famous follower, who generalized his approach into a causal account of evolution and, eventually, of human creativity. In his hands, the complex interplay of variation and selection was responsible for "endless forms most beautiful and most wonderful," including innovations in ideas and technology, as well as those of muscle and bone (Ospovat 1979). In other words: Innovation, in the nineteenth century, came to be seen as a natural consequence of the competition inherent in the interactions that took place in a complex world. Innovation was naturalized.

The psychological origins of modern growth that Baumard proposes would not have surprised Darwin and his followers. This alone should give us pause. Once innovation was naturalized, it became hard to see it as anything other than mental "fitness." But the equation between innovation and evolution, and the idea that both unambiguously represented progress, was an intellectual argument, not an inevitability. Before the early modern period, medieval theorists had their own explanations for how insightful and transformative thinking happened. Some of these processes will seem strange to us – very unlike the Malthusian-Darwinian model. They highlighted memory as a creative instrument, they thought it was important to practice empathy and emotive meditation, and they thought it was impossible to know anything without being receptive to God (Carruthers 1998; Kreiner 2019).

But we still need to take these cognitive models seriously, even if they seem out of date. Historians of science have shown how any given community's ideas about its working methods play causal roles in the *kinds* of work that they pursue and reward (e.g., Cowles 2017; Daston & Galison 2007). That is, their account of how innovation happens interacts, directly and indirectly, with any innovation that actually occurs. Focusing on innovation as an economic virtue overlooks other sorts of creative cognitive work that do not conform to our modern expectations of what progress should look like. In other places and times, the attitudes that Baumard places at the heart of the innovative process – patience, optimism, and curiosity – could be dedicated to "slow strategy" activities that do not seem to have any direct bearing on the macro-economy, like cultivating stronger personal relationships, interpreting a text, and working on the craft of self-discipline and prayer.

It matters how we define innovation and the psychological preconditions for it, because what counts as creative and productive thinking depends on a thinker's own cognitive culture. LHT may point to the tendency of affluent people to tinker and experiment, but it cannot explain why their tinkering takes the forms that it does. When we ask why the Industrial Revolution did not happen earlier, or somewhere else, it amounts to asking why other societies failed to think like us – not just in terms of their neurochemistry, but in terms of their entire conceptual framework (Lerman 2010).

The history of cognition can also make us more alert to the false equivalencies that past thinkers have drawn between cognition and morality. There is an unsettling logic to the proposition that LHT can explain the emergence of asceticism, courtly love, the Republic of Letters, Protestantism, and democracy – or, on the flip side, violence, mistrust, materialism, authoritarianism, and intolerance. One problem is that we find "affluent" groups who are both loving and violent: LHT cannot explain the cross-pollination of courtly love and crusading ethics in the thirteenth century, for example (Sager 2018).

Even more seriously, if we are committed to this model of affluence's effects, we are less likely to notice the violence, mistrust, and materialism that innovation itself engineers. The violence of slavery was part and parcel of capital investment, not an accident of it (Baptist 2014; Johnson 2013). The Atlantic slave system contributed to European affluence, but given the unprecedented scale of its cruelty, it is impossible to take seriously the suggestion that this economy inculcated a "growing empathy toward others" (sect 6.3.3, para. 3). As the global economy emerged and shifted away from organized slavery to murkier and more distant labor systems, European societies only became better at masking their violence, rather than reducing it. We need to be much more precise about what "levels" of "violence" we are measuring, to step outside the historical categories we have inherited, and to be alert to the violence that the affluent wage against people who are outside their own charmed circles.

Baumard's linking of economic history to extra-economic factors, such as cognition, is a welcome one. Histories of the metacognitive dimensions of innovation should be another factor. It is our hope that future collaborative work will reveal the value of this approach to cognitive scientists and historians alike.

Cultural interconnectedness and in-group cooperation as sources of innovation

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Abstract

I argue that the increased rate of innovation in eighteenth-century England cannot be understood without accounting for the unprecedented level of contact between England and other societies as a consequence of sixteenth-century colonialism. I propose cultural interconnectedness and in-group cooperation as two potential alternative explanations for the psychological changes and innovative behavior described by Baumard.

I appreciate Baumard's approach to explaining great patterns of cultural change through proximate causes on human behavior. However, I do not entirely agree with his main hypothesis that the change to an "affluence mindset" was a major factor influencing England's accelerated rate of innovation in the eighteenth century. In this commentary, I propose two alternative explanations for such cultural change. I focus on the influence of cultural interconnectedness and in-group cooperation on the changes in the psychology of English people and their innovative behavior. Finally, I will argue for a shift toward seeing innovation as a social product, instead of the product of isolated individuals.

Cultural interconnectedness

Cultural evolutionary models have demonstrated that cultural interconnectedness is important to generate innovations and promote the evolution of innovation-enhancing institutions (Derex & Boyd 2015; 2016; Henrich 2009). Derex and Boyd (2015; 2016), for example, showed that innovations are more common in groups of individuals than isolated individuals and that partially connected groups innovate more than isolated and fully connected groups. If innovation is a product of cultural interconnectedness, the reason for the increased rate of innovation in England might be simply that England was in the best position to benefit from intensive contact with other cultures: first, because of its long history of being a part of other empires and subject to successive invasions; and second, because it was one of the most successful empires in history (Jackson 2013). Therefore, it is likely that colonialism and the international trade provided the English with different raw materials, other technologies, or cultural products.

In addition, it might be possible that the intensive contact with other cultures might have changed English people's personality in significant ways, particularly with respect to openness and creativity (Schwaba et al. 2018), which could also partially explain changes in the English psychology at the time. In addition, it may as well be that people with more openness to new experiences were also the ones in the position of coming in contact with other cultures. Baumard states that most innovators were merchants, navigators, or lawyers, all professions that may entail higher levels of openness, creativity, and extroversion.

It is very difficult to parse out the influence of cultural interconnectedness from the influence of an affluent environment in modern societies, given that wealthy nations derive their affluence mostly from contacts with other cultures. England's richness is one example, which comes from constant warfare with other societies, colonialism, and international trade. However, it may be possible to test for the influence of cultural interconnectedness in comparison with the affluence mindset by comparing England with other colonial powers at the time in terms of cultural exchange with other societies. Baumard argues that evidence for the importance of affluence, despite cultural exchange, is that developing countries are still catching up with developed ones, even though they have easier access to innovations nowadays. The problem with this argument is that it ignores the continued level of external intervention that many of these countries have suffered, their economic agreements with other more powerful countries, and access to a variety of materials and expertise.

In-group cooperation

The contact with other cultures might have also contributed to the changes in English people's social behavior, thus partially influencing the civilizing process discussed by Elias (2000), one of the authors who inspired Baumard's theory. For example, the increased social trust and cooperativeness toward other in-group members can be the consequence of the contact with other cultures and a heightened sense of competition (Francois et al. 2018). This may partially explain the apparent contradiction in Baumard's assertion that English people were more peaceful among themselves, which it clearly contrasts with the unmentioned violence perpetrated by the English and other European people in their colonies or in their wars. Another aspect of increased cooperation resulting from competition with out-groups is referred to by Elias (2000) as the "monopoly of physical violence," the outsourcing of violence to specific spheres of social life, rendering the display of violence in daily life redundant or illegal. And even though English institutions could have been lenient toward violent crimes such as murder prior to the nineteenth century, it is not entirely impossible that the most violent individuals were either sent to the colonies or benefited from being employed in more violent jobs, thus also contributing to a greater feeling of social trust within the country.

The creation of more complex social identities, as illustrated by the ascension of bourgeois values and education, can also be the indirect product of external politics of England and increasing success in their colonial enterprises. Moreover, as Elias (2000) shows, certain aspects of the civilizing process might also be the product of increased social differentiation between the emerging social classes during the fall of feudalism. Finally, protectionist laws that sought to guarantee England's economic advantage over other countries, such as in the textile industry, could also have helped increase social competition that could have led to more individuals working toward innovative approaches.

Innovation as a social product

Innovations can be defined as incremental changes done to accumulated cultural products that successfully spread in a population (Henrich 2009). In a sense, even when done by single individuals, innovations are the social product of collaboration with previous and current generations. It has been demonstrated that innovation can evolve in species exposed to new, changing environments (Sol et al. 2016) and that partial connection between groups and increased population both lead to more innovative behavior in humans (Derex & Boyd 2016; Henrich 2009). Thus, any hypothesis that claims that psychological changes can explain cultural shifts independently of these other factors should provide strong evidence for that.

England might have had only a small advantage from the start in comparison with other rich countries, and it might be possible that their initial success in dominating other cultures had provided the necessary conditions for the accelerated rate of innovations in the country. Conversely, it might also be that a combination of factors, including an "affluence mindset," could have led to England's Industrial Revolution. Indeed, Baumard does not propose that this particular mindset is the only factor. However, he does not address alternative hypotheses regarding the influence of cultural interconnectedness and in-group cooperation on the rise of English innovations in the eighteenth century. His theory should be tested against other potential explanations within the cultural evolutionary theoretical framework such as those outlined above before it could be proven robust.

Are both necessity and opportunity the mothers of innovations?

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Abstract

Baumard's perspective asserts that "opportunity is the mother of innovation," in contrast to the adage ascribing this role to necessity. Drawing on behavioral ecology and cognition, we propose that both extremes – affluence and scarcity – can drive innovation. We suggest that the types of innovations at these two extremes differ and that both rely on mechanisms operating on different time scales.

In this insightful and interdisciplinary target article, Baumard presents a new perspective on the Industrial Revolution in eighteenth-century England, proposing that affluence, and its accompanying affordances, was responsible for a plastic psychological shift that facilitated innovative behavior. Thus, in contrast to the longstanding adage "Necessity is the mother of invention," Baumard makes a case that opportunity is the mother of innovation. Considering these opposing stances through the lens of behavioral ecology and cultural evolutionary theory, we suggest that both necessity *and* opportunity may be drivers of innovativeness, albeit of different types. We propose that to understand innovation, it is helpful to consider mechanisms operating on two different time scales: a behavioral time scale, on which individuals choose whether to try to innovate or to stick to known behaviors, and a developmental time scale, on which conditions may determine the type of experiences that shape individuals' cognition, thus affecting both their ability and likelihood to innovate.

In behavioral ecology, Life History Theory (Ricklefs & Wikelski 2002; Wang et al. 2009; Wolf et al. 2007) and Optimal Foraging Theory (Caraco 1981; Stephens & Charnov 1982; Stephens & Krebs 1986) are commonly invoked to explain exploratory and potentially innovative behaviors (Aplin et al. 2015; Keynan et al. 2016). However, there is an ongoing debate about the conditions that favor innovativeness, with seemingly conflicting evidence: some findings show that necessity (scarcity) boosts innovation, whereas others, as highlighted by Baumard, support the notion that opportunity (affluence) is the mother of invention (e.g., Benson-Amram & Holekamp 2012; Bokony et al. 2013; Keynan 2016; Laland & Reader 1999; Morand-Ferron et al. 2011; Sol et al. 2012; Thornton & Samson 2012). Thus, Baumard presents research that identifies increased exploration and innovativeness in less-stressed individuals (Andrews et al. 2018; Bateson et al. 2015). In contrast, the *necessity drives innovation* hypothesis (Bokony et al. 2013; Boserup 1965; Laland & Reader 1999; Reader & Laland 2003; Thornton & Samson 2012) suggests that risk-taking, explorative, and innovative behaviors are to be expected in stressed and subordinate individuals with less access to resources, because it is those individuals that must be creative to increase their fitness (Berger-Tal et al. 2014; Houston & McNamara 1999; Kolodny & Stern 2017; McNamara & Houston 1992). We propose that one way to reconcile these opposing findings is to focus not on a single axis of exploration and exploitation trade-offs, but rather to think of adaptiveness of different types of problem-solving strategies in different states of affluence and scarcity. Baumard states that Life History Theory "runs against the common sense according to which 'necessity is the mother of invention'" (sect. 2.4, para. 1). In contrast, we propose that a consideration of the full complexity of the findings in behavioral ecology, cultural evolution, and cognition leads to the conclusion that necessity *and* opportunity can facilitate innovation; we further predict that they should be expected to correlate with different *types* of innovations (Arbilly & Laland 2017; Fogarty et al. 2015; Kolodny et al. 2015a; 2015b).

This point of view may be useful for expanding the ideas brought forth by Baumard with respect to innovativeness and cultural evolution in humans. On short time scales, necessity may be a driving force for goal-oriented, short-time-scale problem-solving behavior, which involves modest risks and payoffs that can be clearly stated or conceptualized. The innovations of this type will be simple conceptually and will likely involve subgoals that are clearly connected to some reward (Arbilly & Laland 2017). On the other hand, opportunity may be a driving force for creative behavior that is directed toward more open-ended problems, where the payoffs are more abstract and not easily defined *a priori*. The innovative solutions of this type may be more complex, involve a hierarchy of multiple conceptual levels, and include subgoals that in themselves are unrewarding (Kolodny et al. 2015c). The innovative behavior in this condition is exploratory in nature. Indeed, the affluent conditions at the onset of the eighteenth century in England could have been particularly well suited for the type of "high-level" innovations that eventually drove the Industrial Revolution.

Alongside immediate need, the ability and tendency to innovate are influenced by dynamics over long time scales: affluent conditions during the development of an individual may allow for extensive exploration, giving rise to a rich cognitive representation of the world (Kolodny et al. 2015b). Moreover, the prospect of future opportunities in itself may encourage exploration and gain of such experience (Berger-Tal et al. 2014). The accumulated experience shapes the cognitive infrastructure that lends itself to innovation when conditions, as discussed above, encourage such behavior. On the flip side, paucity of exploration during development may later constrain the potential for complex, open-ended, or hierarchically structured innovative behavior, even when conditions favor it. Furthermore, limited resources could potentially lead to developmental trade-offs in which an individual might avert metabolic resources from cognitive development to immune function or other physiological needs; stress during development has been linked to learning deficits in a subset of animal studies (Boogert et al. 2013; Crino et al. 2014; Farine et al. 2015; Lemaire et al. 2000; Nowicki et al. 2002), warranting further investigation of its effects on human innovation and learning.

We also note that a discussion of these potential "mothers of invention" in a way that is removed from the cultural evolutionary context of those innovations is naturally limited in its ability to predict population-level processes. For example, both demography and environmental variability are likely to shape the dynamics of human innovation and cultural evolution (Carja & Creanza 2019; Colleran et al. 2015; Fogarty et al. 2013; Fogarty & Creanza 2017; Reader & MacDonald 2003). In addition, human culture is uniquely cumulative and shaped by social interactions between individuals who might use different strategies for innovation (Dean et al. 2012; Derex & Boyd 2016; Derex et al. 2018; Henrich et al. 2016; Lewis & Laland 2012). These complexities suggest a more nuanced characterization of human innovation would be useful.

In many fields, creativity is categorized into multiple subtypes (Fogarty et al. 2015): for example, deliberate versus spontaneous creativity or groundbreaking versus everyday creativity. In previous work, we noted that the field of human cultural evolution has not yet embraced this more nuanced perspective on innovation, and we proposed a number of evolutionary models that consider multiple distinct processes of innovation (Creanza et al. 2017; Fogarty & Creanza 2017; Fogarty et al. 2015; Kolodny 2015a; Kolodny et al. 2016). We predict that motivation for innovation, when tracked along an axis from the most desperate to the most affluent conditions, follows a bowl-shaped curve: High when necessity is great, and also high in times of abundance and leisure, while being lowest in intermediate situations, where fulfillment of basic needs keeps individuals busy but resources are plentiful enough to favor a risk-averse strategy. We further suggest that this interacts with long-term conditions that shape the cognitive infrastructure on which innovative behavior draws. This perspective can reconcile the inconsistency between previous studies and frame Baumard's proposal in a new light: both necessity and opportunity can be the mothers of innovation.

Psychological origins of the Industrial Revolution: Why we need causal methods and historians

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Abstract

Did affluence lead to psychological changes such as reduced discounting, and did these changes facilitate the innovation associated with the Industrial Revolution? I argue that claims of this sort are best made when they can be supported by causal evidence and good psychological measurement. When we have neither identifying variation nor adequate measures, the toolbox of psychologists is not useful.

Baumard puts forward a bold hypothesis about the psychological underpinnings of the Industrial Revolution: The high rate of innovation in England during this period could be the result of an "affluence mindset," consisting of future-oriented time preferences, high levels of optimism and trust, and low levels of materialism. This mindset, in Baumard's view, was generated by the high levels of affluence attained in England at the dawn of the Industrial Revolution. Thus, this account makes two causal claims: First, the affluence experienced by England at the dawn of the Industrial Revolution had particular psychological consequences; second, these psychological variables affected innovation during the Industrial Revolution.

Unfortunately, the evidence for this mechanism is weak. In arguing for a causal effect of affluence on psychological outcomes, Baumard draws on recent work on the psychology of poverty, which suggests that poverty leads to shortsighted time preferences (Haushofer & Fehr 2014; 2018) and has other adverse impacts on cognition (Mani et al. 2013; Mullainathan & Shafir 2013), possibly through psychological mechanisms such as stress (Chemin et al. 2016; Haushofer et al. 2015). However, it is far from clear whether any changes in psychological variables actually occurred during the period in question; and whether they are truly causally responsible for changes in innovation. In principle, methods exist that allow teasing out causal effects from historical data: Natural experiments can make it possible to use instrumental variables or regression discontinuity designs to study the effects of historical events on psychological outcomes. For example, Nunn and Wantchekon (2011) use distance from the coast as an instrument for the number of slaves taken from various regions in Africa, and find that historical slave abductions reduce present-day trust in these areas. However, three factors distinguish efforts such as this one from the evidence Baumard presents.

First, in instrumental variables analyses such as those by Nunn and Wantchekon (2011), care is taken to identify exogenous changes in the independent variable that allow making causal statements about the effects of this variable on the outcome. In Baumard's account, all we are told is that affluence, psychological outcomes, and innovation changed, possibly in sequence. Causality remains a matter of speculation.

Second, in Nunn and Wantchekon's (2011) work, the psychological data come from direct present-day survey evidence on the variables of interest. In contrast, Baumard makes claims about psychological outcomes *in the past*, for which he has no, or only indirect, evidence. This lack of data necessitates some adventurous choices, such as using reading ability as a measure of time preferences. I believe that this is the point where we must recognize the limitations of our methods: When we have neither good (quasi-) experimental variation nor good outcome measures, the toolbox of psychologists is no longer useful. This is a task for historians, who are skilled in finding textual evidence of psychological states in primary sources of the time. We should yield the field to them.

Finally, and relatedly, in Nunn and Wantchekon (2011), distance from the coast arguably affects present-day trust only through the number of slaves taken in the past, rather than through other factors. This so-called "exclusion restriction" is the crucial ingredient of instrumental variables analyses that enables causal statements about, in this case, the effect of the number of slaves taken on present-day trust. In Baumard's mechanism, it is likely to be violated: a change in affluence, even if it does affect psychological variables, would almost certainly also affect innovation through mechanisms other than these psychological variables. Indeed, it is easy to imagine a change in innovation following an increase in affluence that has nothing to do with psychological variables at all. Take again the increase in human capital acquisition that followed the increase in wealth. Baumard wants us to think this was caused by a change in preferences. But is not it equally or more likely that preferences stayed the same, but people were now in a position to implement them? Put differently: an increase in reading ability might have nothing to do with patience, but simply be the result of education becoming affordable.

These difficulties in attributing changes in outcomes to psychological variables, even if they are perfectly observed, illustrate why psychology of poverty literature studies the impact of poverty and its consequences in the lab rather than in the field: As soon as the economic conditions of an experimental group and a comparison group are different, any differences in observed economic behaviors such as investment, time preferences, and so on, could reflect not a true change in preferences, but a change in material circumstances allowing preferences to come to the fore that were there all along. The psychology of poverty literature uses lab paradigms which hold constant economic conditions to avoid this confound (e.g., Haushofer & Fehr 2018). With historical relationships, we do not have the luxury of laboratory-like control, and thus any observed changes in economic behaviors might as well stem from changes in the budget constraint rather than true changes in preferences. This distinction is important because it matters whether we think of the psychology as changing or constant. If the psychology is changing, we truly need to explain the industrial revolution in psychological terms. If, on the other hand, the root cause is a change in the budget constraint, the best explanation is one in economic terms.

How can psychologists study the psychological origins of historical events? First, use empirical methods that allow causal statements, such as instrumental variables and regression discontinuity designs. Second, work with historians to obtain credible measures of psychological variables in the past. Until then, we should stay in the present.

Life History Theory and economic modernity

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Abstract

Baumard's new explanation of the Industrial Revolution shows that Life History Theory holds great potential. Here, I suggest two related hypotheses for examination. One is that there are long-term roots of slow life traits and preferences. The other is that Life History Theory can explain other aspects of economic modernity such as the Scientific Revolution and bureaucratic states. If so, then Life History Theory offers a way to reconcile several bodies of evidence and lines of explanation into a coherent general account of economic modernity.

Life History Theory is a good candidate to produce a unified theory of economic modernity or a great reconciliation on the great enrichment, and Baumard's use of it in Psychological Origins of the Industrial Revolution is a major step toward that end.

There are, however, a couple of weak points in Baumard's theory. One is the claim that growing affluence before the Industrial Revolution caused slower life history strategies to gain ground. Baumard shows that there is an association between affluence and slow life preferences. Lower impulsivity, higher self-control, more optimism or future orientation, greater cognitive ability, and higher trust are positively associated with affluence. This is so in intranational and cross-national comparisons. But it is hard to disentangle which way the causal arrows flow. In the contemporary world, a natural experiment is provided by the extraordinary affluence of oil-exporting countries. If affluence were the main driver, we would expect them to lead the world in slow life traits.

Another point of weakness concerns the peculiarity of England. Baumard concentrates on explaining England's divergence. But England's pioneering role may have been an accident (Crafts 1977). France and the rest of Northwest Europe were similar to England, so any part might have pioneered industry. But, by chance, England happened to specialize in mass market goods (cotton textiles) rather than luxury items. The mass demand for cotton textiles stimulated the adoption of factories and steam power to generate large-scale production. It did not take long for other parts of Northwest Europe to follow suit. It can be added that there is evidence that slow life strategies were also widespread in other parts of Northwest Europe. France, for example, led the way in the demographic transition to lower fertility rates. This suggests that Life History Theory is better suited to explaining not the initial success of England but the swift follow-up in Western Europe and North America, and later Japan.

Nevertheless, Baumard's theory shows that Life History Theory holds great potential. Several areas look promising for further exploration. One concerns the long-term roots of slow life traits and preferences. For example, Galor and Özak (2016) show that there is an association between (a) areas of the world with a long-term orientation as measured by cross-national surveys and (b) areas that had suitable agro-climatic conditions for high-investment, high-return agriculture. They measure the latter using data on crop yields and the length of the growth cycle. In general, growth cycles are short near the tropics, long in higher latitudes. This suggests that long-term orientation (a key part of slow life history) slowly arose as agricultural populations psychologically adapted to longer-growth-cycle farming.

Another possible old source of slow life strategies is the peculiar family and marriage system known as the European Marriage Pattern (EMP). EMP norms included nuclear families, late marriage (so as to be able to form a new household), offspring leaving their parents' household to set up new households, and absence of cousin marriage. This form of loose kinship requires some degree of slow life history because it means deferring marriage and investing in cooperating with non-kin, which has a less immediate but better long-term payoff than cooperation with kin. There is evidence that West Europeans psychologically adapted to a loose kinship system. Schulz et al. (2018) gathered 20 cross-cultural measures and found that Westerners are more individualistic and have higher trust, less conformism, and less tolerance of cheating and nepotism. The authors found that this is associated closely with the length of time a population spent under the influence of the Catholic Church.

If it is true that slow life preferences arose over a long process, they might help explain other developments aside from the Industrial Revolution. Before the Industrial Revolution there was the Scientific Revolution. Without science, industry could not have happened. The keystone technologies of steam power and then, later, of electrical and chemical industries were inconceivable without scientific knowledge. Thus, the question arises whether a growing slow life history fraction of the population was responsible for the rise of science in the seventeenth and eighteenth centuries. As with the Industrial Revolution, there is a prima facie association. The slow life personality desires to cooperate, and science required trust and public sharing of information; desires learning and intellectual understanding, which was critical to science; engages in self-control and a long-term orientation, which are necessary for scientific inquiry. The rise of science also required the spread of an idea that there are things to be discovered, that not all knowledge was found by the ancients, that it is possible to accumulate knowledge. But this too would not take root unless a critical mass of people had the slow trait of an orientation toward the future rather than the present. Life History Theory could shed light on the Scientific Revolution.

Closely associated with economic modernity is state-making. The creation of a modern political order commonly accompanied the great enrichment. A strong state was particularly prominent in catchup development of countries such as Japan, Russia, South Korea, and most recently China. It is possible that Life History Theory can illuminate this question. If the political elite of a country are slow life history strategists then they are likely to have the traits of cooperativeness, self-control, prudence, long-term orientation, and cognitive ability. An effective state depends above all on the cooperativeness of the elite, willing to put aside factional interests willing also to exercise restraint in not dominating the non-elite. This may be a clue as to why state-making and the great enrichment tended to go together: they both arise from similar sources.

These indications point to Life History Theory as a relatively parsimonious way to reconcile several bodies of evidence and lines of explanation into a coherent general account of the roots of economic modernity – a great reconciliation about the great enrichment.

There is little evidence that the Industrial Revolution was caused by a preference shift

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Abstract

The idea, based on Life History Theory, that the Industrial Revolution was a positive feedback process wherein prosperity induced prosperity-promoting preference shifts is just an intriguing speculation. The evidence does not distinguish this explanation from simple alternatives. For example, increased prosperity may have freed up time for individuals to engage in innovative activity and increased the benefits from doing so.

The evidence and arguments that Baumard brings to bear in support of this explanation for the Industrial Revolution do not uniquely distinguish it from plausible alternatives. A very simple one is that increased prosperity freed up more time for individuals to engage in innovative activity and increased the benefits from doing so. This possibility is consistent with the great bulk of the evidence adduced in support of the preference-shift explanation.

The Life History approach focuses on the effects of prosperity on the development of psychological characteristics. To focus on an alternative, set aside any shifts over time in the inherent preferences and attitudes. Instead, consider how prosperity directly affected the costs, benefits, and constraints on innovative activity for mature individuals with given psychological traits. Someone who is at the edge of starvation has little time to engage in new discoveries, and is compelled to focus on generating immediate payoffs. In contrast, just as Baumard has argued, innovation requires a short-run sacrifice of time, effort, and resources, in the hope of long-term payoffs. So greater prosperity encourages a greater focus on exploration rather than exploitation.

This explanation is very similar to Baumard's thesis, and exactly for this reason, most of the evidence adduced as confirming Life History Theory is equally consistent with the alternative explanation. But this explanation does not require that prosperity have any effect on the development of psychological traits.

To put this another way, the very same argument that justifies the Life History Theory argument – that prosperity favors the lifetime development of long-term oriented psychological traits – also suggests, even if no such effect exists, that mature individuals will find it optimal to follow long-term oriented strategies. Instead of developmentally malleable psychological traits, all that is required is that (mature) humans be responsive to costs and benefits in their environments.

Specifically, the key to the Life History Theory explanation for the Industrial Revolution is that in favorable environments (prosperity during a young sensitive period) it tends to be optimal for an organism to become developmentally disposed toward a focus on strategies that have high long-term expected payoff. In such an environment, it tends to be the case that such strategies can be followed without causing short-term disaster. But for exactly the same reason, even if prosperity had no effect on development, it increases the benefit for mature adults with given psychological traits to focus more on long-term strategies.

Baumard is aware of this issue, and explicitly addresses it in section 6.3.3 of the paper. However, it is surprising that this alternative is addressed so briefly. The evidence that Baumard adduces in favor of the Life History Theory explanation as against this alternative is limited to a single page. Baumard provides insightful discussion of the changing nature of English novels of the period, attitudes toward slavery, romantic fiction, and portraiture. But these points by no means rule out the alternative explanation that we propose here, nor, for that matter, any other theories of the Industrial Revolution.

Even if these shifts occurred for the Life History Theory reasons that Baumard proposes, it is possible that the personality changes brought about by prosperity were minor relative to the incentive effects that we propose. In particular, attitudes toward slavery, romantic fiction, and portraiture are all cultural products (as is the Industrial Revolution), and it is possible that shifts in personality were amplified more by cultural evolutionary processes more for slavery attitudes and the arts than for technological discovery and adoption.

Furthermore, it is also possible that the incentive effects in our alternative hypothesis – which directed people toward a greater focus on strategies with long-term payoffs – also affected attitudes toward slavery and artistic styles, for essentially the same reason as that which Baumard proposes. For example, consider the shift of the English novel toward a focus on long-term planning. The only difference in our possible explanation for this shift from Baumard's is that this shift, instead of deriving from a shift in people's personalities, could derive from an incentive-induced shift in people's interest and attention toward long-term strategies.

Importantly, Baumard also points out that Life History Theory empirical research has documented that many important traits, including those relating to time discounting and trust, are in part set during childhood or in utero. However, even a mature individual with fixed internal attitudes toward consumption over time (what economists call "time preference") will follow different *strategies* in trading off the present with the future if the individual faces different *opportunities*. Someone who is prosperous can afford to save more than someone at the edge of starvation, and (more speculatively) may have a greater interest in novels about making plans for the distant future.

There are, in principle, ways in which the two explanations are distinguishable. The Life History Theory explanation suggests that what is crucial is the environment individuals experience during an early sensitive period, rather than just generalized prosperity that impinges directly upon adults, as well as juveniles. So to explore Baumard's theory more deeply, it would be valuable to develop evidence about age-specific environmental shifts and their effects.

Also, the explanation we offer is far from the only possible alternative to the Life History Theory. For example, general increase in prosperity, perhaps complemented by reduced costs of transportation or communication, can widen social networks, facilitating collaboration and recombination of ideas. This also suggests that an increase in prosperity may have a positive feedback effect.

To sum up, the Life History Theory explanation for the Industrial Revolution is plausible, and may be right, but much clearer evidence would be needed to distinguish this explanation from alternatives.

The affective origins of the Industrial Revolution

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Abstract

We suggest in this commentary an emotional origin of the Industrial Revolution. Specifically, increased living standards directly preceding the Industrial Revolution produced increased happiness and subjective well-being that, in turn, fueled the explosion of innovation and economic growth experienced in industrial England.

Happy people are creative, innovative, and productive people (Diener 2012; Isen 2008). People are generally happier when their basic material needs are met (Diener 2012). We suggest that increases in affluence and living conditions experienced directly prior to the Industrial Revolution produced increased subjective well-being and happiness in pre-industrial England. This increase in subjective well-being and happiness, in turn, produced greater creativity that ultimately led to the explosion of innovation and economic growth experienced during the Industrial Revolution.

There are, of course, no data to tell us the degree of subjective well-being and happiness at the time of the Industrial Revolution. Nevertheless, we can make some educated guesses based on current theory and research on subjective well-being and happiness. This research shows that increased living standards, not unlike those experienced directly prior to the Industrial Revolution, reliably produce increased subjective well-being and happiness, both when looking across nations and when looking within nations over time (Diener 2000; Sacks et al. 2010). Citizens of richer countries, for example, experience greater subjective well-being and happiness than those of poorer countries. Looking within countries this research reveals that richer citizens are happier than poorer citizens (Sacks et al. 2010). More critically, perhaps, is longitudinal research showing that as living conditions (e.g., economic and income growth) improve within a country, the subjective well-being of its citizens also improves (Sacks et al. 2010; Veenhoven & Vergunst 2014). In summary, then, the economic growth and improved living conditions citizens of England experienced prior to the Industrial Revolution documented by Baumard are just those predicted by current research to produce increased subjective well-being and happiness.

Increases in subjective well-being and happiness reliably produce increases in creativity, innovation, and productivity (Isen 2008; Lyubomirsky et al. 2005). Happy people, for example, focus on the big picture (Gasper & Clore 2002). Happiness leads individuals to form more inclusive categories in which atypical exemplars (e.g., feet) are assigned to the category vehicle (Isen & Daubman 1984). Individuals who are happy are better able to entertain ideas about how objects might serve different purposes and thus are more successful at solving Duncker's candle problem and creative insight problems (Isen et al. 1987). Happiness and higher subjective well-being have both been shown to produce greater productivity at work (Lyubomirsky et al. 2005). Not only does happiness produce more flexible and creative cognition, but it also produces a greater self-control, optimism, sociality, and trust in others (Lyubomirsky et al. 2005). And, finally, happiness has been shown to produce a focus on future rewards and benefits (i.e., happiness reduces time discounting; Ifcher & Zarghamee 2011).

Additionally, the longevity of the Industrial Revolution can also be partially attributed to increases in happiness and subjective well-being through its impact on children, who would grow up to continue the innovation and economic growth seen during the period. The improved living standards prior to and during the Industrial Revolution resulted in positive childhood experiences and there is research suggesting that happiness facilitates creative play and divergent thinking in children (Russ 1999). It has been found that inducing positive affect in eighth grade students improved problem-solving skills (Greene & Noice 1988). Furthermore, longitudinal research has found that creative play in first and second grade children leads to greater divergent thinking over a 4-year period, suggesting that this impact of affect on childhood play is stable over time and predictive of creativity later in life (Russ et al. 1999).

In summary, the consequences of happiness and higher subjective well-being almost perfectly overlap with the mix of psychological factors Baumard suggests produced the Industrial Revolution: increased optimism, reduced time discounting, greater self-control, optimism, sociality, trust in others, creativity, and productivity.

We end by emphasizing that we do not doubt that the psychological origins outlined in the target article played a significant role in producing the economic growth observed during the Industrial Revolution. We merely suggest that there may have been important, and overlooked, affective origins of the Industrial Revolution.

Interrelationships of factors of social development are more complex than Life History Theory predicts

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Abstract

Life History Theory (LHT) predicts a monotonous relationship between affluence and the rate of innovations and strong correlations within a cluster of behavioral features. Although both predictions can be true in specific cases, they are incorrect in general. Therefore, the author's explanations may be right, but they do not prove LHT and cannot be generalized to other apparently similar processes.

Nicolas Baumard explains the origins of the Industrial Revolution on the basis of Life History Theory (LHT). As presented by Baumard, LHT makes two important predictions. First, the relationship between wealth and the rate of innovation is monotonously positive and probably exponential (because wealth gives rise to innovations that further increase the wealth of the population). Second, there is a uniform relation between affluence, innovation rate, quality of life, prosocial behavior, optimism, long-term investments (e.g., education), social trust, and several other variables, all being negatively correlated with violence and materialist views.

I agree that both predictions may be perfectly true for some populations or some epochs of human development, but they are false in general. Counterevidence can be found even in the target article itself. Thus, optimism and open-mindedness tend to decrease in contemporary Western society despite its affluence (sect. 6.1). Ironically, Baumard uses this fact to argue against "cognitive" explanations of the Industrial Revolution without noticing that they work even harder against his own explanation. The supposed negative correlation between affluence and materialism (sect. 5.4) implies that the richest people do not even want to be rich.

Every nonmonotonous function contains monotonous segments; when we look at one of such segments, we can believe we are observing a monotonous function. This is what LHT does. The prediction of monotonicity can be questioned in several ways. In many societies the largest cultural achievements have been realized by the second-wealthiest social group but not by the wealthiest one. As Baumard rightly notices, most inventions and discoveries were made by representatives of the wealthy middle class – but much less by people from the high class. To my knowledge, only 1.5% of Nobel Laureates in the natural sciences were of noble origin, although very many of them received nobility on account of their scientific achievements.

An obvious nonmonotonous factor is urbanization. At the transition from pre-industrial to industrial society, the growth of towns was accompanied by increasing morality and decreasing violence; now, however, large cities are characterized by rates of crime and violence that dramatically increase with city size. Another intervening variable may be maternal care. In present-day affluent societies, more women realize their human potential in their jobs. On the other hand, maternal absence (calculated as the percentage of mothers who regularly work) is positively related to the rate of murder (e.g., Huang 1995).

The relationship between wealth and subjective well-being (or "happiness"), albeit monotonously positive, does not fully agree with LHT predictions. Within the upper income range, further increases in income result in ever smaller increments of happiness; the function demonstrates a curvilinear trend with a tendency to saturation (e.g., Diener et al. 1993).

Baumard rightly argues that affluence may have given rise to Protestant Work Ethics (PWE: sect. 6.1), but it can also cause three other kinds of ethics: Wealth Ethics, which does not correlate with PWE, and Leisure Ethics and Welfare Ethics, which are *negatively* related to PWE (Furnham & Rose 1987). In a similar vein, Adler (1997) indicated that economic growth can result in a "doing-oriented" culture (which facilitates innovations), but also in a "being-oriented" culture (which hampers innovations). The same society can be doing-oriented at a certain step of its economic development but became being-oriented at a later step.

Halpern (2001) showed that antisocial morality contains two different factors, called "self-interest" antisociality (e.g., tolerance to cheating on tax, to keeping money found, to self-interest lying) and "illegal" antisociality (e.g., tolerance to driving under alcohol, littering, political assassinations). Only the former factor significantly correlated with the national crime rate and with behavioral variables predicting the crime rate (young age, male gender, city size); the latter did not. Both factors did not correlate with income, and the correlations of the "self-interest" antisocial factor with social trust and education level were significant but very low (–.08 and .04, respectively). These data clearly contradict LHT's predicting that prosocial behavior (both factors), high income, high education, high social trust, and low crime rate all should go hand-in-hand. This prediction of uniform relationship is further in conflict with the data of Tang and Koveos (2004), who showed that innovation entrepreneurship is differently related to economic growth rate in high-, middle-, and low-income countries.

The societal predictors of innovation rate appear to be much less simple than Baumard suggests on the basis of LHT. Dakhli and De Clercq (2003) performed a large-scale investigation of three innovation indices (number of patents, research and development [R&D] investments, high-tech exports) as functions of human capital (i.e., skills), social trust, cooperation, country size, income gap, and norms of prosocial behavior (the same items as in the two factors of Halpern, see above). First, social trust was not a single variable; rather, trust in one's fellows (generalized trust) did not correlate with trust in social institutions. Generalized trust had a positive impact on R&D expenditures but not on high-tech exports, whereas the opposite was true for institutional trust. In agreement with LHT, all innovation indices were robustly related to human capital. In strong contrast to LHT, however, high-tech exports were *negatively* related to prosocial behavior (standardized $\beta = -.51$, $p < .001$). To explain this finding, the authors question the monotonicity assumption. They suggest that moderate prosocial behavior might facilitate innovative activity, but too much of it is related to social conformity. Strong innovations can require the ability to violate norms.

To summarize, I admit that LHT can explain a lot about what happened in Northern Europe in the eighteenth century, but attempts to generalize the explanation result in inconsistencies. According to an old joke, the shape of a cow can, in a first approximation, be regarded as a simple sphere. However, by the next step, we see that her tail, ears, and hooves do not fit into the oversimplified theoretical framework. A good theory is not one that meets many confirming cases but, rather, one that does not meet any disconfirming case (Popper 1963). Therefore, LHT is not a good theory.

England first, America second: The ecological predictors of life history and innovation

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Abstract

We present data from 122 nations showing that Baumard's argument on the ecological predictors of life history strategies and innovation is incomplete. Our analyses indicate that wealth, parasite stress, and cold climate impose orthogonal effects on life histories, innovation, and industrialization. Baumard also overlooks the historical exploitation of other nations which significantly enlarged the "pooled energy budget" available to England.

Baumard provides an intriguing application of Life History Theory by analyzing a major economic transition in world

Table 1. (Luoto et al.) *Materials and sources*

Variable	*N* countries	Year	Reference
GDP per capita[a]	122	2016	World Bank statistics;
			CIA Factbook
Parasite stress[b]	122	2002	Fincher and Thornhill 2012
Atmospheric cold demands[c]	122	1960–1990	Van de Vliert 2013
Atmospheric heat demands[d]	122	1960–1990	Van de Vliert 2013
Industrialization[e]	119	2004; 2007	Van de Vliert and Murray 2018
Global Innovation Index	109	2018	Dutta et al. 2018
Economic Complexity Index	122	2016	The Atlas of Economic Complexity 2017
Intelligence[f]	122	N/A[e]	Lynn 2002, 2012
Adolescent fertility rates[a,g]	122	2014	UN Statistics Division 2017
Population size[a]	122	2016	World Bank statistics
Population density[a]	122	2016	World Bank statistics
Distance from Brussels[a]	122	2017	European Commission 2018; see Luoto 2019

[a] Natural logarithm transformed because of high skew.
[b] Parasite stress data were collected from Fincher and Thornhill (2012), who used the World Health Organization (WHO) variable Infectious Disease DALY for the year 2002 to collate a variable called *combined parasite stress*.
[c] *Atmospheric cold demands* are coded as the sum of the absolute downward deviations from 22°C for the average lowest temperature in the coldest month, the average highest temperature in the coldest month, the average lowest temperature in the hottest month, and the average highest temperature in the hottest month (Van de Vliert 2013).
[d] *Atmospheric heat demands* are the sum of the absolute upward deviations from 22°C for the average lowest temperature in the coldest month, the average highest temperature in the coldest month, the average lowest temperature in the hottest month, and the average highest temperature in the hottest month (Van de Vliert 2013).
[e] A factor score that represents the extent to which countries are engaged in industrial and service activities versus the agrarian sector (agriculture, fishing, and hunting).
[f] The relevant time frame of the data is unspecified in the source material.
[g] Births per 1,000 women aged 15–19.

history. Despite the merits of his model, it is deficient in several important ways. Materials and sources used in our analyses are listed in Table 1.

Pooled energy budget

Baumard points out the increased wealth in England compared with rival nations, causally modelling this in Figure 2 through gradual technological accumulation. The "gilt elephant in the room" overlooked by Baumard is of course England's colonial history and slave trade (de Zwart & van Zanden 2018). The concept of "pooled energy budget" (Kramer & Ellison 2010; Krams et al. 2019) is useful for modelling English wealth and the nation's life history transition documented by Baumard. By exploiting the natural and human resources of other nations, by drawing energy from the resources and labour of other peoples, the English were able to substantially increase the pooled energy budget available to their own people. An important factor that sets England apart from other colonial powers is that its American colonies had a substantial production capacity and unprecedented population growth. Most material goods to fuel this growth were imported from England. This meant that England, which monopolized trade across the Atlantic, was able to pool a large amount of resources from its American colonies (de Zwart & van Zanden 2018).

We argue that any life history model that seeks to explain the Industrial Revolution needs to account for this enlarged pool of energy that correspondingly disadvantaged other populations (such as native Americans and Africans, through genocide and slave trade). An increased energy budget can explain individual- and population-level variation in central life history parameters, including marital and reproductive timing, investment in human capital formation, and immune function (de Pleijt 2018; Foreman-Peck & Zhou 2018; Krams et al. 2019; Luoto 2019). It is not sufficient to argue that "gradual technological accumulation" led to the higher pooled energy budget available for the English prior to the Industrial Revolution: it is also important to acknowledge the exploitation of other nations in that causal process.

Different kinds of environmental harshness impose unique influences on innovation, life histories, and industrialization

A further problem in Baumard's article is the myopic discussion of environmental harshness that overlooks the important selective role of climate on human behaviour. In short, Baumard argues that harsh environments favour fast life histories while in stable, predictable environments people can invest in the future, thus developing slower life histories. Baumard's model oversimplifies predictions that arise from life history accounts of human behaviour and innovation. It neglects the important influence that climate has on time orientation, life history strategies, innovative capacity, and economic development (Luoto 2019; Luoto et al. 2019; Orosz et al. 2017).

Cold environments may impose selection pressures on organisms to invest in long-term orientation and cultural innovations (Luoto 2019; Luoto et al. 2019, and references therein). Accordingly, the associations between atmospheric cold demands and various measures of innovation and industrialization are uniformly positive, strong, and significant (Table 2). Cold climate significantly

Table 2. (Luoto et al.) *Correlations among variables*

	Variable	1	2	3	4	5	6	7	8	9	10	11
1.	GDP per capita											
2.	Parasite stress	**–.73**										
3.	Cold demands	**.44**	**–.67**									
4.	Heat demands	**–.32**	**.38**	**–.64**								
5.	Industrialization	**.81**	**–.81**	**.53**	**–.35**							
6.	Global Innovation Index	**.84**	**–.69**	**.56**	**–.42**	**.67**						
7.	Economic complexity	**.77**	**–.70**	**.58**	**–.39**	**.70**	**.86**					
8.	Intelligence	**.73**	**–.76**	**.66**	**–.45**	**.66**	**.81**	**.79**				
9.	Adolescent fertility rate	**–.74**	**.77**	**–.56**	**.28**	**–.70**	**–.78**	**3.75**	**–.75**			
10.	Population size	–.15	**.34**	–.15	.08	**–.25**	.01	.04	.01	.11		
11.	Population density	.05	–.13	–.18	.03	.05	.08	**.27**	.08	–.15	**.24**	
12.	Distance from Brussels	**–.45**	**.60**	**–.57**	**.34**	**3.49**	**–.55**	**–.56**	**–.48**	**.61**	.16	–.21

Table 3. (Luoto et al.) *Multiple linear regression models without control variables*[a]

	Industrialization	Global innovation index 2018	Economic complexity 2016	Intelligence	Adolescent fertility ($\log_e$)
GDP	**.474**	**.755**	**.582**	**.397**	**–.424**
Parasite	**–.450**	.039	–.119	**–.267**	**.375**
Cold	.018	**.215**	**.238**	**.282**	–.203
Heat	–.021	–.066	–.007	–.048	–.125
R^2	.77	.75	.67	.70	.68
VIF	<3.23	<3.47	<3.25	<3.25	<3.25
n	119	109	122	122	122

[a]Standardized coefficients of four independent variables (GDP per capita, parasite stress, cold demands, heat demands) on five dependent variables (industrialization, innovation, economic complexity, intelligence, adolescent fertility). No control variables introduced in the model. For coefficients in boldface, $p < .01$.

predicts variation in innovation, economic complexity, and intelligence even when the Gross Domestic Product (GDP) per capita, parasite stress, and heat demands are simultaneously entered into statistical models predicting innovation (Table 3). These effects remain significant when controlling for population size, population density, and distance from Central Europe (Table 4; see Luoto 2019, for a rationale for using these controls). Importantly, cold climates may also select for slower life history strategies (Luoto 2019; Luoto et al. 2019), as suggested by the significant negative correlation between cold demands and adolescent fertility ($r = –.56$, Table 2). These findings provide additional support for a theoretical framework that links cold climate with psychological dispositions and behaviours related to slow life history strategies and innovation (Luoto 2019; Luoto et al. 2019).

It is noteworthy that heat demands impose less influence than cold demands on industrialization and innovation (Tables 2–4). Although cold climate significantly predicts *increases* in industrialization, innovation, and intelligence, heat demands and parasite stress are negatively associated with these variables (Table 2; see also Van de Vliert & Murray 2018). These findings show that not all types of environmental harshness have similar effects on innovation and economic development. Cold demands impose selection pressures that are qualitatively different from those imposed by heat demands, parasite stress, and morbidity-mortality (Barbaro & Shackelford 2017; Van de Vliert & Murray 2018). Baumard's generalization that all harshness has similar effects on life history strategies is inconsistent with existing theory and findings.

We point out these findings, not because we think they necessarily explain the specific life history transition that Baumard describes in England, but because Baumard's argument is inconsistent with what is known about the influence of climate on human psychological and behavioural dispositions. We agree with Baumard that the two mechanisms of natural selection and adaptive plasticity do not work at the same time scale, and that adaptive plasticity may be more suitable for explaining the specific instance of the Industrial Revolution. However, when viewed globally, and with recourse to deeper evolutionary time, adaptive plasticity explains innovation and economic development only partially (Luoto 2019; Luoto et al. 2019). Any model on life history, time orientation, and innovation is incomplete without taking into consideration the cross-culturally robust influence of cold demands on human psychological dispositions and behavioural outcomes.

Whether climate can explain the psychological origins of the Industrial Revolution is a more specific question. We do not think this is the case. Although cold periods predict longitudinal variation in innovation with moderate accuracy, the Industrial

Table 4. (Luoto et al.) *Multiple linear regression models with three control variables*[a]

	Industrialization	Global innovation index 2018	Economic complexity 2016	Intelligence	Adolescent fertility ($\log_e$)
GDP	**.472**	**.725**	**.596**	**.354**	**–.399**
Parasite	**-.461**	.030	–.021	**–.422**	**.338**
Cold	.009	**.249**	**.368**	**.280**	–.159
Heat	–.024	–.058	.042	–.051	–.130
R^2	.77	.81	.78	.76	.72
VIF	<4.86	<5.47	<4.82	<4.82	<4.82
n	119	109	122	122	122

[a]Standardized coefficients of four independent variables (GDP per capita, parasite stress, cold demands, heat demands) on five dependent variables (industrialization, innovation, economic complexity, intelligence, adolescent fertility) when controlling for population size, population density, and distance from Central Europe. For coefficients in boldface, $p < .01$.

Revolution was not preceded by particularly severe cold periods (Fig. 1B in De Dreu & van Dijk 2018). Cold demands may be a more significant factor in predicting *global* patterns of innovation and economic development (Luoto 2019; Luoto et al. 2019) rather than explaining the specific tide of events that led to the Industrial Revolution.

Despite its shortcomings, there is much to commend in Baumard's model. Understanding the various pre- and postnatal factors that affect the calibration of life history strategies (Luoto 2019; Luoto et al. 2019) and the importance of the "pooled energy budget" that was accomplished through English exploitation of other nations' natural and human resources will make Baumard's life history model biologically more compelling and historically more accurate.

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Using big data to map the relationship between time perspectives and economic outputs

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Abstract

Recent studies have shown that population-level time perspectives can be approximated using "big data" on search engine queries, and that these indices, in turn, predict the per-capita Gross Domestic Product of countries. Although these findings seem to support Baumard's suggestion that affluence makes people more future-oriented, they also reveal a more complex relationship between time perspectives and economic outputs.

Baumard argues that affluence leads to people becoming more future-oriented, which, in turn, allows for greater innovation efforts. This is an intriguing hypothesis, but also one that requires the right kinds of population-level data to test it. Fortunately, researchers can now use search engine data to map human behaviors and derive proxies of human cognition at the aggregate level (Moat et al. 2014; 2016).

The growing availability of data on the Web offers novel ways to estimate the characteristics of time preferences at the population level. For example, according to one prominent decision making theory (Olivola & Chater 2017; Stewart et al. 2006), the curvature of the delay discount function (i.e., the rate at which delayed rewards are devalued compared with immediate rewards) is determined by the relative frequencies with which people are exposed to delays of various lengths, and this, in turn, can be estimated from the contents of the Web. Specifically, researchers have used the frequencies of mentions of various delay lengths (e.g., "1 day," "2 days," …, "1 week," "2 weeks," etc.) to estimate this exposure, and shown that the resulting distribution predicts the shape of one of the most empirically established delay discount functions (Olivola & Chater 2017; Stewart et al. 2006). One could, in principle, carry out separate searches of this sort for different countries (e.g., by counting the relative mentions of delay lengths in the most prominent news sources within each country) to estimate their (aggregate) discount functions and see whether this predicts their levels of innovation and economic performance.

In fact, with our colleagues, we have proposed novel proxies of aggregate (population-level) time perspectives, which can be estimated for each country (Noguchi et al. 2014; Preis et al. 2012). Specifically, we used Google Trends to calculate the relative volume of searches for future years (e.g., searching for "2020" in the year 2019), past years (e.g., searching for "2018" in the year 2019), and present years (e.g., searching for "2019" in 2019), within each country. The ratios of these search volumes provide indices of the extent to which the online search behavior of citizens in a given country is focused on the future relative to the past (Preis et al. 2012), as well as the future relative to the present and the past relative to the present (Noguchi et al. 2014). These indices can be obtained for many countries, and for a number of different years, going back more than a decade. As such, they constitute useful approximations of aggregate time perspectives – the extent to which people are focused on the past, present, and future – for each country.

It turns out these time perspective indices are strongly correlated with gross domestic product (GDP) per capita – a key measure of a country's economic output. Preis et al. (2012) calculated the ratio of future-year searches to past-year searches for 45 different countries and found that the resulting "future orientation" values predicted per capita GDP ($r = .78$). Noguchi et al. (2014) examined four other indices: the ratio of future-year searches to present-year searches ("future focus"), the ratio of past-year searches to present-year searches ("past focus"), the deceleration in the volume of past-year searches ("past time horizon"), and the acceleration in the volume of future-year searches ("future time horizon"). They found that three of these four indices (future focus, past focus, and past time horizon) were significant predictors of country per capita GDP. Specifically, higher future focus and past time-horizon values, as well as lower past focus values, were all independently associated with higher per capita GDP. In sum, this work shows that one can generate indices of population-level time perspectives using "big data" from activity on the Web, and that the resulting indices are strongly correlated with economic output.

These findings seem to support Baumard's suggestion that affluence makes people more future-oriented. However, these studies also reveal that the relationship between time perspectives and economic outputs is more complex than he suggests. For example, the extent to which a population is focused on the past (vs. present) and the extent to which it is focused on the future (vs. present) both *independently* predict economic output, albeit in opposite directions (Noguchi et al. 2014). Moreover, the rate at which a population shifts its focus from the past to the present over time (past time-horizon) also positively predicts economic output (Noguchi et al. 2014). Finally, we echo Baumard's caution against drawing strong conclusions regarding the direction of the relationship between future orientation (or other time focus indices) and economic performance without appropriate, additional evidence, as each could plausibly affect the other: greater affluence could lead to people becoming more future-oriented; however, a greater focus on the future could also lead to greater affluence, by helping people consider the future consequences of their decisions (Read et al. 2017), and thus maximize their long-term wealth.

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Note

Many causes, not one

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Abstract

This comment focuses on difficulties in establishing causality among various phenomena present in early modern Europe at the beginning of the Industrial Revolution. It concludes that, rather than focus on a single cause out of many candidates, we should consider the possibility of a set of mutually reinforcing causes, among which those suggested by Life History Theory may be included.

The origins of the Industrial Revolution come second perhaps only to the origins of the First World War as a topic attracting contributors who are both numerous and distinguished. As with the Great War, Nicolas Baumard's enjoyable paper faces the challenge of persuading us not only that his hypothesis is right, but also that we understand precisely what distinguishes it from those of rival scholars. In this field, there is (relatively) little disagreement about the various phenomena that occurred in England in the eighteenth century: the growth in incomes, the development of various institutions increasing the protection given to private property, the increase in trade, the decline in violence, the increase in innovation.

The disagreement between scholars is partly about timing: Recent evidence from Humphries and Weisdorf (2016) based on calculations of annual rather than daily wages places the growth of labor incomes well before the mid-eighteenth century favored by the previous consensus. But mainly it is about causality: Was the increase in innovation an independent cause of increasing incomes, or was it (as claimed by Baumard) mainly the consequence of prior high incomes? It is extremely hard to say anything about causality, either in the numerous studies cited here about life history or in the studies showing that various apparently growth-reinforcing attitudes occurred in England both before and during the eighteenth century.

To take the former studies first, I doubt anyone would dispute that "Individuals living in conditions of affluence tend to have lower rates of time discounting, to be more optimistic, and to be more conscientious and trustful" (sect. 3.6, para. 2). The issue is to what extent priori affluence causes these other characteristics; it seems plausible that the causality runs in both (indeed, in all) directions. Correlational studies do not become evidence about causation through being cited in large numbers.

Nor are twin studies the magic bullet Baumard seems to think they are: even if a study (sect. 3.6, para. 1) "found that individuals with higher birth weight (within pairs of identical twins) are more likely to participate in the stock market (a proxy of risk-taking preference)," we do not know whether the higher birth weight caused later participation in the stock market through changing risk preferences or through other mechanisms (such as inducing parents to give preferential treatment to the heavier child, causing that child to become more prosperous than its twin).

This example prompts the question, valid for the latter studies, as well, of which proxies to pick for risk preference and time discounting among the hundreds potentially available. Why use participation in the stock market when this is correlated with many other things that are not risk preferences? Similarly, why use literacy rates in early modern Europe as evidence of diminished time discounting rather than, say, pointing to the reduced rate of cathedral building as evidence in the other direction? The willingness to design and build cathedrals has as good a claim as any other to be a proxy for long-term thinking. It is hard to avoid the suspicion that, if cathedral building had appeared to favor the Baumard hypothesis, it would have been cited, but because it does not, it was not.

The very wealth of possible correlates of the unobserved variables of Life History Theory means that Baumard several times loses sight of the aim of the exercise, which is to explain why England had its Industrial Revolution before any other country. In using literacy rates as evidence of lower time discounting, he cites the fact that England had higher literacy than France, while treating as of minor importance that England had lower literacy than Germany or Scandinavia. Similarly, he makes a great deal of Manuel Eisner's (2001) evidence that English homicide rates began falling in the later Middle Ages, and of the fact that "on the eve of the Industrial Revolution … England was still ahead of the rest of Europe" (sect. 5.3, para. 1) – but he cannot have it both ways. What matters for his hypothesis is the *change* in homicide rates over time, and this occurred spectacularly across Europe (including in Italy), even if in England these were lower than elsewhere from the sixteenth to the nineteenth centuries.

This is not to dispute the plausibility of the hypothesis, but if rates of time discounting were falling everywhere in Europe, as they probably were, this phenomenon will not explain the English origins of the Industrial Revolution. And several things make me doubt their relevance to the question of English origins. One is that innovation is the fruit of a tiny subset of the population, whose affluence had been little correlated with the general living conditions of the population prior to the eighteenth century. The French upper classes were probably more affluent than their English counterparts in the sixteenth through eighteenth centuries, so it is not a lack of affluence that explains their unwillingness to engage in innovation.

A second reason for skepticism is that England's greater rate of urbanization produced affluence for those who survived childhood but at the cost of horrendous rates of infant mortality for those who grew up in the cities. It is not clear why Life History Theory should focus only on the affluence of those who survive to adulthood and not on the *ex ante* improbable fact of their survival.

Most importantly, the dominant fact about the modern world is that sooner or later the Industrial Revolution took place everywhere. As Baumard points out, quoting Deirdre McCloskey, the increase in prosperity it brought about was massive, far greater than it seems reasonable to attribute to any single cause. Even if increases in risk taking preceded increases in innovation, a claim that is at best unproven, the extent of innovation seems out of proportion to the alleged cause. This very strongly suggests that we are seeing the mutual and cumulative reinforcement of several different causes. That one such cause was the change in attitudes predicted by Life History Theory is a reasonable conjecture, and Baumard's paper, although always stimulating, would have seemed more convincing to me if it had been framed in this light.

Timing is everything: Evaluating behavioural causal theories of Britain's industrialisation

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Abstract

Baumard's thesis that the English Industrial Revolution can be explained by Life History Theory's predictions for psychological development is a progression of much literature in economic and social history. However, the theory suffers from its reliance on increasingly fragile data indicators for "wealth" and its focus on "innovation" as new research begins to explore sectoral dynamics in long run growth.

Throughout most of the late twentieth century, the Industrial Revolution was conceived of as caused by a structural change in the relationship between capital and labour, but as Cannadine (1984) described, each generation finds its own features in the mirror of the Industrial Revolution. In an age of tech start-ups and rapid growth trajectories in new markets, historians and economists of the last two decades have approached the Industrial Revolution as a case of technological innovation-led growth, and sought the origins or cause of that innovation as a kind of "Holy Grail" (Crafts 2010), the origins of modern economic growth itself. Douglass North called for cognitive science to serve as the basis for breakthrough in economics and social sciences almost a quarter of a century ago (North 1996), so it is surprising that it has taken so long for someone to present a coherent thesis for the psychological origins of the innovation-led Industrial Revolution. The Baumard thesis is, in many ways, a natural progression of much literature in economic and social history, and the article itself describes the close fit between Life History Theory's predictions for behaviour and much of that influential literature.

The thesis as presented relies on the given fact of the relative greater wealth of the English by the dawn of the eighteenth century. As Baumard acknowledges, although there is a rich literature that asserts this, it is not considered proven, and there is currently an increasing body of new research from all over Europe challenging its traditional foundation – comparative wage data (Humphries & Schneider 2019; López Losa 2016; Mocarelli 2019; Stephenson 2018). The focus on relative wealth and its psychological effects raises at least three important and unanswered questions about the occurrence of industrialisation. The first is that of location: Although the Dutch Republic is mentioned, the anomaly of the lack of Dutch industrialisation, or technological innovation, through the Golden Age when clearly Dutch wealth outstripped that elsewhere in northwestern Europe is not addressed, nor are the concomitant questions about what the psychological development and effects of that Golden Age, and decline, might have been.

Second is the level and kind of wealth or income, and whose it was that led to innovation. As recent research indicates (Stephenson 2019) unskilled men in London may have had incomes of merely half what Allen (2009b) calculated. This raises the question of the distribution of wealth, income and capital, and its psychological effects, particularly because inequality is also such an important contemporary question (Piketty 2014). Was there a difference between the wealth or income and psychological motivations of "inventors" and the artisans and apprentices who "tinkered"? Did their relative wealth matter? How does inequality impact on reward orientation, materialism, and cooperation? If innovators arose only in a particular class or group, then is the greater overall wealth of England necessary for the theory to hold? Moreover, if that were the case might there be other institutional and social factors beyond wealth which would cause the psychological progressions? This is essentially the subject of McCloskey's bourgeois theses cited which have proven so hard to model or confirm. It should be pointed out that the histories of actual innovators who created new technology, machines, and ways of working like Richard Arkwright tell a story of very different behaviour to that predicted by Life History Theory (LHT) (Styles 2016).

Third is the major question of timing. It is possible that the model Baumard advances does not require that England was the wealthiest state but its presentation here *does*. The essential question of why the affluence mindset occurred to bring about innovation in England in the eighteenth century rather than elsewhere is not addressed other than by the (shaky) fact of England's predominant wealth at that time. In not being able to predict the timing of innovation, nor explain a lack of it elsewhere the theory fails to make a contribution to the causes of the industrial revolution, rather the paper makes some well-founded and well-researched speculative associations between LHT's predictions and what is known of England's eighteenth-century trajectory. It should be noted that current research on the actual level of growth in output shows that the timing question may render the thesis irrelevant. England's growth in the eighteenth century was slower than that of the seventeenth, with changes in output rates only beginning to take off after 1821 (Crafts and Mills 2017).

There is an obvious gap in the classic economic history literature discussed: de Vries's *Industrious Revolution* (2008), which although touched on is only so in relation to working hours. The essence of the deVries thesis is that household behaviour, consumption, and individual actors' choices changed. Surely the household would be a better agar plate in which to test LHT against economic behaviour – if only for the probate accounts? The other glaring absence here is that of the eighteenth-century history of the emotions, a growing field, but one where the rich social and cultural history of the eighteenth century can already offer many cases and sources (Hewitt 2017; Reddy 2001).

If necessity is *not* the mother of invention after all – as LHT seems to say – then there is probably no better century than the eighteenth in England in which to try and test the thesis. The paradoxes of eighteenth-century wealth and destitution, militarisation and enlightenment, revolution, and persistence will undoubtedly be forever produced and reproduced by historians. It remains to be seen whether innovation and well-being will be one of them, however.

Energy, transport, and consumption in the Industrial Revolution

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Abstract

We question Baumard's underlying assumption that humans have a propensity to innovate. Affordable transportation and energy underpinned the Industrial Revolution, making mass production/consumption possible. Although we cannot accept Baumard's thesis on the Industrial Revolution, it may help explain why complexity and innovation increase rapidly in the context of abundant energy.

Baumard's conclusions are based on a specific view of history that should be made clear, and an assumption that remains implicit. The view is that the Industrial Revolution was the product of a historical accident, the fact that Britain was comparatively prosperous in the eighteenth century, leading members of the upper classes to innovate. Because this prosperity remains unexplained, and as the Industrial Revolution itself produced increasing prosperity, the thesis is unsatisfactory. We argue that Britain's prosperity derived from the rebound after the Black Death, followed by the transition to the coal-based economy.

Using Life History Theory (LHT), Baumard postulates that prosperity in eighteenth-century Britain unleashed innovation and, thus, the Industrial Revolution. Baumard's implicit assumption is that humans have an inherent propensity to innovate, and that we will do so when circumstances are favorable. One problem with this assumption is that it is conditioned by our circumstances today. Every member of an industrial society experiences frequent, institutionalized innovation, leading us to think that this is normal. Furthermore, we are socialized to value innovation, believing it to be something to which people aspire. In fact, innovation as we know it today is recent in human history. Our species, *Homo sapiens*, has a history of at least 300,000 years. Yet over these 300 millennia, systematic innovation is a phenomenon of only the past two centuries. Our ancestors in the Paleolithic experienced periods of tens of thousands of years with little technological change (Ambrose 2001). That is, for periods of tens of thousands of years our ancestors did not innovate. Existing technologies were sufficient. Recent hunter-gatherers, such as the Kalahari San, work little to support themselves, and have been characterized as "the original affluent society" (Sahlins 1972). LHT, as employed by Baumard, would suggest that such people should innovate. Yet they do not. In recent history there have been periods of hundreds to thousands of years with little technological change in many areas of life. Among recent peasant societies, the most prosperous households preferred leisure to extra work (leading to extra income) or to innovation (Chayanov 1966). Recent research suggests that humans succeed best, not by innovating, but by copying (Rendell et al. 2010). This history undercuts Baumard's thesis by illustrating that innovation is not an intrinsic human characteristic. Systematic innovation exists only in specific historical circumstances, including abundant energy and commercial competition (Tainter et al. 2018).

Before the development of fossil fuels, the majority of humans were caught in a poverty trap, a self-reinforcing condition that keeps people in a condition of material want. In the past, part of the mechanism of the poverty trap was the cost of land transport. Data from the Roman period, with an economy similar to that of medieval Europe, illustrate the point. A wagon load of wheat would double in value with a land journey of only 480 km, a camel load, in 600 km. Transport by road was 28 to 56 times more costly than by sea. It cost less to ship grain from

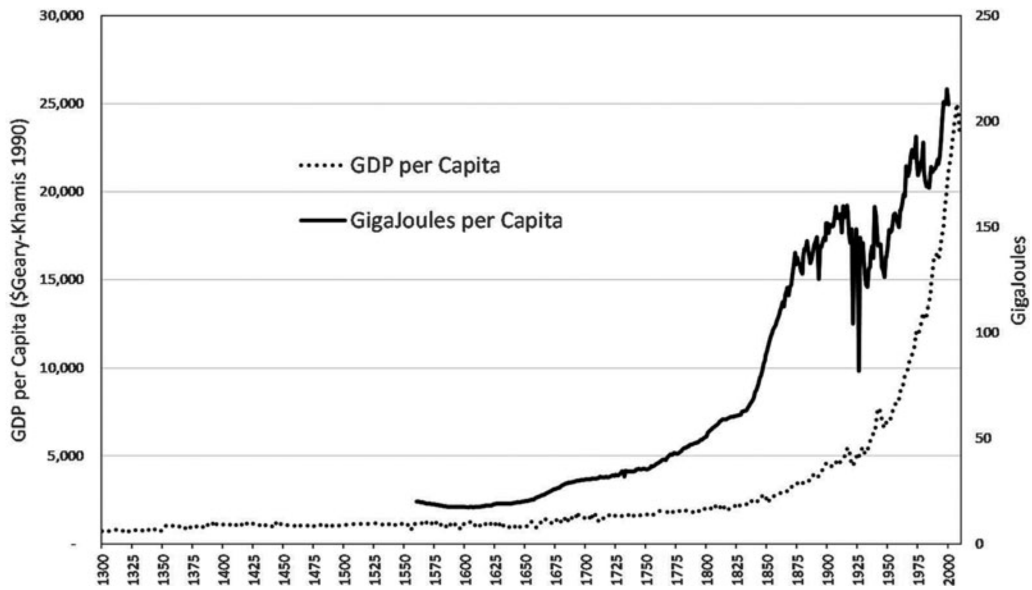

Figure 1. (Tainter & Taylor) Abundant energy supplied by coal lifted the constraints of annual solar productivity, allowing rapid increases in complexity and innovation during the Industrial Revolution. (Data are from Broadberry et al. 2015; Fouquet & Broadberry 2015; Maddison Project 2013; Warde 2007.)

one end of the Mediterranean to the other than to cart it 120 km. The only goods that could profitably be transported long distances were luxury goods. The bulk of the population, existing on their own agricultural production, could not afford such goods (Jones 1964, pp. 841–44). Similarly, in England, coal shipped over land doubled in price in a distance of 10 miles (Wrigley 2010, p. 44). An industrial revolution can find sufficient customers, and lift living standards globally, only if people can access and afford its products. This was possible only with the development of canals and railroads (Smil 1994, pp. 195–99; Wrigley 2010, pp. 39, 44). Transport and energy were more fundamental to the Industrial Revolution than any propensity to innovate.

Was affluence necessarily a driver of the psychological and behavioral changes that led to high rates of innovation during the Industrial Revolution? Prior to the Industrial Revolution, several of the countries Baumard discusses experienced notable increases in affluence (Fouquet & Broadberry 2015). The rise in Gross Domestic Product (GDP) per capita between 1300 and 1400 in Great Britain, The Netherlands, and Italy shown in Baumard's Figure 5 was a result of the Black Death, which left survivors with greater land and capital (Fouquet & Broadberry 2015). In these cases, circumstances of affluence produced neither an industrial revolution nor high rates of innovation.

Humans have rarely had abundant energy. Prior to the use of coal, energy consumption was based mainly on annual solar productivity. Growth and change happen slowly in systems with such limited energy, and complexity emerges slowly. Abundant energy changes this. According to the Maximum Power Principle, excess energy in a system is quickly consumed, leading to growth, change, and/or accelerated processing of resources (Hall 2004). When humans possess extra energy, as in the present era, it generates complexity (Tainter & Patzek 2012). Innovation is one way complexity increases. While societies saw increases in affluence in earlier times, the difference in 1700s England was the availability of energy. We argue that the inexpensive and abundant energy supplied by the distribution and use of coal underpinned the material, societal, and psychological changes of the Industrial Revolution (Tainter et al. 2018; Taylor & Tainter 2016). Figure 1 charts the increasing GDP per capita of England and Wales alongside per capita energy consumption. High-quality, inexpensive energy created positive feedback cycles in innovation, population, agriculture, transportation, and urbanization (Wrigley 2010), each requiring still more energy. Abundant energy was able to support the costs of this increasing complexity, including innovation. Although we cannot concur that Baumard has explained the origin of the Industrial Revolution, his application of LHT may help to clarify some of the growth in societal complexity of the past two centuries.

A needed amendment that explains too much and resolves little

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Abstract

Baumard's application of Life History Theory to explain the origins of economic growth is a needed amendment to incentive-based explanations of modern economics. However, even though it is grounded in evolution, the theory does not do enough to specify the relevant evolutionary mechanisms. As such, it accommodates too many alternative historic scenarios, yet remains unable to explain divergent regional patterns of economic growth.

The dominant incentive-based apparatus of modern economics and political economy has not been able to offer a satisfying explanation of the greatest single fact of economic history – the sudden and unprecedented economic growth of the living standards that started two centuries ago. Baumard's article is a welcome contribution to recent literature that goes beyond the standard, incentive-based economic and institutional explanations of the causes of the Great Enrichment.

Baumard's application of Life History Theory (LHT) to the Great Enrichment, if right, not only connects the dots in accounts provided by McCloskey (2016a), Mokyr (2016), and Clarke (2007), but also opens the door to other potential applications of the theory that the author does not entertain. For example, LHT may be able to explain the settling of America, as the settlers exhibited precisely the initiative, optimism, and long-term horizon that Baumard argues were crucial for the enrichment of England.

Nevertheless, Baumard's attempt to explain Great Enrichment using a theory ultimately grounded in evolution raises several questions.

Most glaringly, Baumard's work fails to properly engage the issue of causality. According to him, the necessary condition for a portion of a population to switch to a long-term strategy is a previous improvement in the living standards, such as that present in and before the eighteenth century in England. The long-term strategy is thus a consequence as much as a cause of economic growth. Perhaps aware of the shortcoming, Baumard resorts to endogenous growth theories, a family of economic models that capture the interplay and mutual reinforcement of various elements of economic growth, "in which growth and technological progress are endogenous and do not require any external input" (sect 6.2, para. 2). This maneuver, however, does not shed any new light in the question of causality but simply moves the explanation a few centuries back: England in the eighteenth century grew rich because England in the fifteenth century started growing rich.

Indeed, if LHT switch is causally important, we would expect visible implications for other times and places. How can one explain large differences in economic growth in different regions? Since the 1970s, poorer China has grown much faster than the relatively affluent Latin America. Once prosperous countries, such as Argentina in the early 20th century and Venezuela more recently, experienced considerable declines. For growing economies, the LHT hypothesis, as espoused by Baumard, implies that there is a critical level of per capita income after which growth accelerates. Baumard does not tell us what this level could be, and historic economic growth trajectories of different societies up to the present do not seem to support the existence of such thresholds.

Although the premise of Baumard's approach is that the Great Enrichment is a unique period of history and an enduring scientific puzzle (i.e., exponential economic growth starts in eighteenth-century England), the approach is simultaneously sympathetic to the view that "there is actually nothing special about the Industrial Revolution. The rate of innovation has been increasing exponentially since the Neolithic, and the Industrial Revolution is just the moment at which the exponential nature of the acceleration became undeniable" (i.e., exponential growth with a starting point in Neolithic; sect 6.2, para. 3). That Baumard's theory approach can accommodate so easily these wildly different curves suggests that the approach lacks specificity.

And there is a good reason for it. The theory lacks specificity because Baumard never uses a crucial part of LHT – Darwinian fitness. LHT does not merely say that humans could be more or less forward looking (as Baumard extensively documents), but also ties these strategies to environmental and ultimately evolutionary pressures they are facing. LHT was developed as a way to reconcile flexibility in animal behavior with evolutionary theory by showing that, for various organisms, in various circumstances, it pays off, from a Darwinian perspective, to tinker with parental and reproductive investment over lifetime.

Yet, at no point does Baumard connect short-term versus long-term strategies in humans with their consequences for Darwinian fitness. Although persuasively demonstrating such connections is probably beyond the scope of a single article, his argument would be stronger if a plausible mechanism was presented: What exactly would increasing proportion of long-term strategists in the eighteenth-century England gain in terms of Darwinian fitness?

How abundant resources would lead to more long-term versus short-term strategies is likewise unclear. Would not individuals employing short-term strategies while free-riding on wealth generated by long-term innovators be at an evolutionary advantage? Should not the abundance of resources that make survival more likely and parental investment less necessary therefore favor reproducing as early and as often as possible? In fact, evolutionary theorists have argued that large environmental carrying capacity (of the sort created by exponential economic growth) would favor *r* versus *K* selection – concepts analogous, respectively, to short- and long-term life strategies (Taylor et al. 1990).

Looking at the past two centuries at the most basic level one gets a sense that human choices are ever more removed from fitness maximization. Rather than experiencing explosive population growth in line with available resources, population in the richest societies in human history is, or soon will be, in decline. Natural selection, fitness maximization, and other concepts from evolutionary theory do not appear naturally suited for explaining these changes – they make them appear puzzling. We are therefore skeptical that theoretical accounts grounded in evolutionary theory, such as LHT, are ultimately going to be helpful in our understanding of recent history.

Affluence boosted intelligence? How the interaction between cognition and environment may have produced an eighteenth-century Flynn effect during the Industrial Revolution

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Abstract

Cognition played a pivotal role in the acceleration of technological innovation during the Industrial Revolution. Growing affluence may have provided favourable environmental conditions for a boost in cognition, enabling individuals to tackle more complex (industrial) problems. Dynamical systems thinking may provide useful tools to describe sudden transitions like the Industrial Revolution, by modelling the recursive feedback between psychology and environment.

Baumard offers an interesting perspective on the psychological origins of the Industrial Revolution by combining Life History Theory (LHT) with sociological, historical, and economic information. However, he downplays the importance of what may well be the most immediate candidate for explaining a revolution most aptly characterized by its shrewd inventions and smart solutions: increases in intelligence. In particular, Baumard dismisses the possibility that secular gains in cognitive ability, produced by the unprecedented affluence of eighteenth-century England, may have played a role, because "individuals living in scarcity will not show impaired cognitive or behavioral performance" (sect 2.4, para. 4). However, this thesis does not sit well with the evidence. At least five sources of evidence support a robust association between affluence and cognitive ability, which is likely to be at least partly causal in nature.

First, human and animal studies have shown that poverty and related daily stressors limit cognitive ability via a biological causal pathway (Hackman et al. 2010). Stress in mothers during pregnancy increases prenatal risks comprising fetal growth and neurodevelopment, and continuing postnatal stress subsequently leads to less parental involvement and care, with adverse (epi)genetic and neurodevelopmental consequences. Second, chronic stress is correlated with a less stimulating home environment, while animal studies have shown the positive effect of environmental enrichment on brain organization and function (Kempermann et al. 1997). Third, poverty impedes cognitive capacity directly through a psychological pathway (Mani et al. 2013): people simply make less prudent and wise decisions when under financial stress. In addition, because the continuing stressful daily hassles of a life in poverty result in limited cognitive resources, it is difficult to escape negative feedback loops of shortsighted decisions and adverse consequences in order to focus on long-term goals (Haushofer & Fehr 2014). Fourth, there is strong evidence showing massive secular gains in intelligence across the world during the twentieth century (Flynn 1987; 2007), and the speed and size of these changes almost certainly imply a causal role for an increasingly wealthy environment, probably through a feedback mechanism with ability (Dickens & Flynn 2001). Fifth, reported associations between geographical location and cognitive performance are largely predictable from scores of the relevant locations on United Nations and World Health Organization standards of living which are direct indicators of affluence (e.g., water quality, nutrition; Wicherts et al. 2009).

Thus, contrary to Baumard's claim, the empirical evidence does in fact support a link between affluence and the distribution of cognitive ability in the population via a host of biological, psychological, and environmental pathways. This accords well with modern conceptions of intelligence, in which IQ is not seen as fixed property but as an index that reflects the outcome of mutualistic developmental relations between biological, psychological, and environmental processes (Van der Maas et al. 2006). Anything that promotes the growth rate or carrying capacity of one or more of these processes can increase the end state of cognitive ability. Combining these lines of evidence, it seems likely that the cognitive ability distribution has undergone a shift in the unprecedented period of affluence preceding the Industrial Revolution. In our view, the direct relevance of cognitive ability to the technical innovations that triggered the Industrial Revolution strongly suggests that it should be included in the explanation of this process.

Importantly, such an explanation need not be contradictory to the LHT account that Baumard proposes. On the contrary, if a slow general increase in living standards provided the physical and environmental conditions for a boost in intelligence across the English population, this implies that, with accruing time and money, general health could improve and the home environment could, in turn, provide a more stable context with more cognitive stimulation (e.g., reading and education), supported by the invention of devices that themselves promote these processes (e.g., technology that requires cognitive effort for its successful operation). With a changing economic system, it may indeed have become more adaptive for individuals to invest their intelligence and attention in complex (industrial) problems that required patience and a focus on long-term goals, as Baumard suggests – challenges that require and train executive functioning. As such, technological progress and the subsequent increased standards of living may have become a dynamic intertwined self-reinforcing process of cognitively prepared individuals and cognitive demanding industrial-technological challenges. If so, the interaction between cognitive ability and the environment may have instantiated essentially the same multiplier effect that is generally seen as the most likely explanation for the Flynn effect as observed in the twentieth century (Dickens & Flynn 2001).

This feedback process may itself have catalysed the sudden acceleration of technological innovation that characterizes the Industrial Revolution as a revolutionary rather than an evolutionary process. Interestingly, abrupt transitions are commonly observed in complex systems with feedback and often show characteristic behaviour ("early warning signals") prior to such transitions (Scheffer et al. 2009). Therefore, viewing history through the lens of complex dynamical systems may offer an explanatory and data-analytic framework that may reveal considerable insight into the nature of the Industrial Revolution and, possibly, other historical processes (Scheffer 2009). In our view, it is likely that cognitive ability would have to be a key element in such a framework.

The wealth→life history→innovation account of the Industrial Revolution is largely inconsistent with empirical time series data

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Abstract

Baumard proposes a model to explain the dramatic rise in innovation that occurred during the Industrial Revolution, whereby rising living standards led to slower life history strategies, which, in turn, fostered innovation. We test his model explicitly using time series data, finding limited support for these proposed linkages. Instead, we find evidence that rising living standards appear to have a time-lagged bidirectional relationship with increasing innovation.

Baumard proposes that the high levels of innovation observed in the United Kingdom during the Industrial Revolution stem from a process whereby increasing living standards promoted a shift to slower life history strategies – including decreases in fertility and increases in long-term oriented psychological characteristics such as optimism – which, in turn, prompted greater innovation. We find the proposal interesting and consistent with previous theory regarding effects of ecology on human life history behaviors. We applaud the author for proposing an explanation for sociocultural change rooted in evolutionary biology (see Varnum & Grossmann 2017; 2019). However, in the target article these proposed linkages are not assessed using data which allow rigorous empirical tests.

Baumard's theory seeks to explain not only the increase in innovation that produced the first Industrial Revolution in Britain, but also purports to provide a broader explanation for how rising resource levels may lead to increases in innovation by promoting a slow life history strategy. High-quality year-by-year time series data on living standards, life history-relevant behaviors, and innovation are sparse or unavailable before the latter part of the first Industrial Revolution; thus we opted to test Baumard's theory (1) using time series data on these markers for the United Kingdom (Gross Domestic Product [GDP] per capita, optimistic language, patents, and unique book titles) during a time span that included the late period of the first Industrial Revolution to the end of the second Industrial Revolution (1790–1913), and (2) using time series data on a broader set of these markers (GDP per capita, optimistic language, birth rates, patents, trademark applications, and unique book titles) for a broader time span in the United States, where the first Industrial Revolution started somewhat later than in Great Britain, covering the end of the first Industrial Revolution up to the putative third Industrial Revolution underway in recent years (1790–2015). To assess the direction of these relationships we used cross-correlation function analyses with first-order differencing, because relevant time series showed strong levels of first-order autocorrelation, zeroing in on lagged relationships up to ± 25 years. When high degrees of autocorrelation are present in time series, detrending the data before performing analysis is highly recommended (Jebb et al. 2015; McCleary et al. 1980; Tiokhin & Hruschka 2017), although alternative methods which explicitly model the linear trends may be used (Jebb et al. 2015; Varnum & Grossmann 2017; 2019; Varnum et al. 2019). All results including zero-order correlations, CCF analyses with and without first differences detrending, and all data can be accessed at the Open Science framework (OSF, available at: osf.io/ws6by).

Our findings either provide limited support for Baumard's theory or explicitly contradict it. In the United Kingdom, we find evidence of links between resource levels and life history in the direction opposite Baumard's predictions, such that increases in GDP per capita preceded decreases in optimistic language in books (we view optimism as a psychological characteristic associated with slow life history) at lags of 1 and 9 years (based on the Google Books United Kingdom corpus). When examining the relationship between optimistic language in books and the number of patents (a typical marker of innovation), the relationship was negligible, whereas the relationship between changes in optimistic language and the number of unique book titles per million inhabitants (another marker of innovation) was bidirectional and in the direction opposite that predicted by Baumard's theory – increases in unique book titles preceded a decrease in optimism at lags of 16 and 21 years, and decreases in optimism preceded increases in unique book titles at a lag of 4 years. Analyzing the data without detrending did not lend stronger support for Baumard's hypotheses, either (results available at https://osf.io/ws6by).

In the United States, we observe evidence largely inconsistent with Baumard's theory. Changes in optimism-related language (from the Google Books United States corpus) preceded increases in per capita GDP at a lag of 24 and 25 years. Further, there was no significant relationship between GDP per capita and birth rate (a marker of fast life history). We also find evidence in the direction opposite Baumard's theory regarding life history and innovation, such that increases in birth rates (a marker of fast life history) preceded increases in patents per million at a lag of 10 years, and increases in birth rates preceded increases in the number of unique book titles published at a lag of 19 years. Further, changes in birth rates were only negligibly related to changes in trademark applications per million (another marker of innovation). Finally, changes in optimistic language in books were largely unrelated to changes in patents, number of unique book titles, or trademark applications per million. Again, analyzing the data without detrending did not lend stronger support for Baumard's hypotheses (results available at https://osf.io/ws6by).

Baumard's theory suggests that living standards *indirectly* promote innovation. Notably, an indirect relationship can mean a path mediated through another cultural psychological process, as well as a lagged effect, with time as a mediator itself. Therefore, we sought to test whether there might be an indirect relationship between these variables in the latter sense, as well. In the United Kingdom, the strongest relationship between increases in GDP per capita and the number of patents occurred at a lag of 21 years, and we also find that increases in patents preceded increases in GDP per capita at a lag of 10 years, suggesting a bidirectional relationship between these variables. In the United States, increases in GDP per capita preceded increases in patents at lags of 14, 22, and 25 years (although there was also a negative lagged correlation such that increases in patents preceded decreases in GDP per capita at a lag of 25 years). Notably, increases in innovation may also lead to increases in living standards. In the United Kingdom, increases in unique book titles preceded increases in GDP per capita at a lag of 15 years. In the United States, increases in trademark applications preceded increases in GDP per capita at a lag of 8 years, and there was also a significant contemporaneous relationship. Links between GDP per capita and unique book titles were negligible in the United States. In sum, these results suggest that overall there may be a fairly consistent lagged, and possibly bidirectional, relationship between living standards and innovation.

Taken together, analyses of time series data from the United Kingdom and the United States provide inconsistent evidence for Baumard's first claim – that rising resource levels led to slower life history behaviors – and either fail to support or contradict his second claim – that a shift to slower life history led to greater innovation, at least during the (late) first and second Industrial Revolutions and into the putative third Industrial Revolution underway in recent years. However, our analyses do provide support for lagged, often bidirectional, associations between living standards and innovation. Based on our initial tests, it appears that more sophisticated analytical models, or additional factors, are necessary to explain the rapid increases in innovation that occurred during the late first Industrial Revolution, as well as during the second and third Industrial Revolutions.

Slowing life history (K) can account for increasing micro-innovation rates and GDP growth, but not macro-innovation rates, which declined following the end of the Industrial Revolution

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Abstract

Baumard proposes that life history slowing in populations over time is the principal driver of innovation rates. We show that this is only true of micro-innovation rates, which reflect cognitive and economic specialization as an adaptation to high population density, and not macro-innovation rates, which relate more to a population's level of general intelligence.

Data indicate that certain aspects of life history (*K*) have been historically slowing in Western populations, as Baumard observes – a trend that continues to the present. This process results from a combination of persistent genetic selection favoring those with higher levels of *K* (Woodley of Menie et al. 2017a) and epigenetic changes stemming from reduced levels of environmental risk (Mace 1999). Previous work has investigated the role of secular life history slowing in the modernization sequence and concomitant sociological and economic trends (Figueredo et al. 2017; Hertler et al. 2018; Woodley of Menie et al. 2017b). Understanding how increasing *K* in industrialized populations relates to changing rates of innovation requires drawing a distinction between *macro-innovation* and *micro-innovation*, however. The former pertains to foundational developments in major domains of human accomplishment (such as science, medicine, and engineering) that multiple historians convergently rate as prominent (e.g., the development of the plough or nuclear fission technology), whereas the latter pertains to incremental developments and refinements of macro-innovations (e.g., new versions of smart phones) (Huebner 2005; Woodley 2012).

Prior research has found that increasing *K* likely drives micro-innovation, as *K* predicts the ability to invest resources into the cultivation of narrow cognitive abilities – potentially allowing individuals to specialize economically with respect to the development of facets of macro-innovations (Woodley et al. 2013). *K* has been shown to also be predictive of economic growth, both directly and indirectly, as more economic specialization in response to increased population density and concomitant micro-innovative capacity among the workforce translates into greater national comparative advantage, as indicated by several major indicators of macroeconomic diversification in employment, production, and exports (Figueredo et al. 2017). Rising *K* has furthermore been identified as a basis of the *Flynn effect* or the secular increase in performance on certain IQ measures over time (Pietschnig & Voracek 2015; Woodley 2012), and this effect has in turn been identified as a driver of economic growth (Pietschnig & Voracek 2015; Rindermann & Becker 2018; Woodley 2012). Across time, *K* may be independent of macro-innovation rates, which are dependent instead upon a population's level of *general intelligence* (*g*) – the ability to solve complex abstract and evolutionarily novel problems (Woodley of Menie et al. 2017b). IQ is heterogeneous, and the Flynn effect involves gains on only specialized and narrow cognitive abilities; conversely, measures that track temporal trends in simple endophenotypes of *g* (such as simple reaction time and working memory), or highly heritable proxies (such as patterns of vocabulary usage), reveal the opposite pattern, that is, long-term decline (Sarraf 2017; Woodley of Menie et al. 2017b).

Among individuals within Western populations, there are only weak correlations between *g* and *K* measured using psychometric instruments, indicating that they relate to largely distinct neurological systems (Woodley of Menie & Madison 2015). This is further evidenced by the observation that in modernized Western populations, as was mentioned, *K* is under *positive* directional selection (Woodley of Menie et al. 2017b), whereas in those same populations, *g* is under *negative* directional selection (hence the long-term decline; Reeve et al. 2018). The opposing phenotypic trajectories (rising *K* and decreasing *g*) can hence account for the rise in micro-innovation rates (as tracked by rising GDP per capita) and the decline in macro-innovation rates following the end of industrialization in Western nations. Consistent with this possibility, robust temporal correlations have been established between multiple convergent indicators of declining *g* and macro-innovation rates in the United States and United Kingdom across the nineteenth and twentieth centuries (Woodley of Menie et al. 2017b). But the temporal association between *K* and micro-innovation rates is less well established. Here we examine this association using temporal correlations involving a latent chronometric *K*-factor composed of convergent trends in the utilization frequencies of both low- and high-*K* indicating vocabulary items tracked using Google Ngram Viewer; life expectancy, infant mortality, and total fertility rates (from Figueredo et al. 2019); and a measure of per capita macro-innovation rates and GDP per capita (from Woodley of Menie et al. 2017b), predominantly sampled from the United States and United Kingdom, covering 104 years (1889–1993).

Consistent with expectations, there is a high-magnitude temporal correlation between *K* and GDP per capita in the United

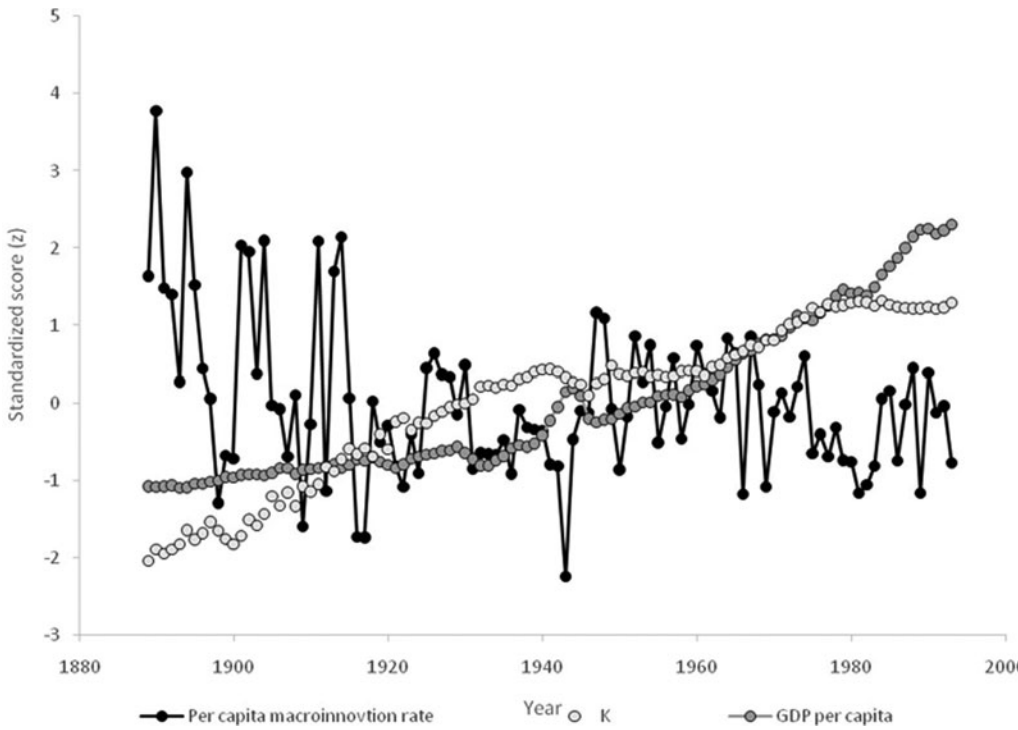

Figure 1. (Woodley of Menie et al.) Temporal trends in per capita macro-innovation rates and GDP per capita, as well as a *K*-factor, sourced primarily from the United States and United Kingdom populations, spanning the years 1889 to 1993.

States and United Kingdom ($r = .85$, 95% confidence interval [CI] = .79–.90). A modest-magnitude negative temporal correlation between *K* and per capita macro-innovation rates is also present ($r = -.39$, 95% CI = –.54 to –.21), consistent with the expectation that macro-innovation rates are not driven by changes in levels of *K*, but by changes in other population-level parameters (such as average *g*, which is declining throughout this period; Woodley of Menie et al. 2017b). GDP per capita and macro-innovation rates are weakly negatively correlated ($r = -.24$, 95% CI = –.41 to –.05). That these trends are largely independent of one another is consistent with Fogel's (1964) observation that macro-innovations (such as the development of railway) did not add much value to the economy of the United States in and of themselves, with most of the value deriving from novel refinements and applications (micro-innovations) of these technologies (i.e., improvements in track manufacturing techniques, emplacement of new railway tracks).

These results highlight the pitfalls of failing to distinguish between macro-innovation and micro-innovation in models of modernization and should help to enhance the precision of Baumard's argument, by connecting it to prior relevant theoretical and empirical research in this area (e.g., Woodley of Menie et al. 2017b, in which an alternative life history theoretic model of modernization is refined and tested). These empirical findings also allow for additional claims of Baumard's to be tested. For example, inasmuch as postmaterialistic values started to rise primarily in the "post-industrial" era of the West (Inglehart & Welzel 2005), and insofar as this trend may be connected to rising *K*, it is unlikely that these values globally benefit innovation rates, in that their relevant effects, if there are any, seem to be restricted to micro-innovation.

Author's Response

Psychological origins of the Industrial Revolution: More work is needed!

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Abstract

I am grateful to have received so many stimulating commentaries from interested colleagues regarding the psychological origins of the Industrial Revolution and the role of evolutionary theory in understanding historical phenomena. Commentators criticized, extended, and explored the implications of the perspective I presented, and I wholeheartedly agree with many commentaries that more work is needed. In this response, I thus focus on what is needed to further test the psychological origins of the Industrial Revolution. Specifically, I argue, in agreement with many commentators, that we need: (1) better data about standards of living, psychological preferences, and innovation rates

(sect. R1); (2) better models to understand the role of resources (and not just mortality) in driving cultural evolution and the multiple aspects of the behavioral constellation of affluence (sect. R2); and (3) better predictions and better statistical instruments to disentangle the possible mechanisms behind the rise of innovativeness (genetic selection, rational choice, and phenotypic plasticity) (sect. R3).

R.1. More data are needed

I shall start with the issue of data and, perhaps more importantly, with the issue of quantification. I shall argue that the lack of quantification tends to generate some confusion in the conceptualization of the Industrial Revolution. Without any quantification, we are indeed tempted to focus on a few "macro-inventions," such as the steam engine, the flying jenny, and the coke blast furnace, or to conceptualize the Industrial Revolution as the shift between two radically different kinds of economic processes, from agriculture to industry, from organic (animal, human energy) to inorganic (fuel, water) energy, or from human to mechanical processes of production. But there were much more than a few macro-inventions during the Industrial Revolution. As I said repeatedly in the target article (following historians of technology), the Industrial Revolution is best conceptualized as an increase in innovativeness: there were more innovations in every domain, in textiles, in metallurgy, in mining, et cetera. Likewise, dichotomic classifications (agriculture/industry, organic/inorganic) are always problematic. It is difficult to pinpoint a period for the beginning of the rise of industry, machines, and inorganic energy. What we observe instead is a continuous process of increasing innovativeness and increasing mechanization.

Maybe the best way to understand the nature of the Industrial Revolution and the need for quantification is to have a look at the evolution of income per capita in England over the last 800 years (Broadberry et al. 2015, Fig. 1). From the perspective of GDP per capita, the Industrial Revolution looks hardly like a revolution. It is only the first noticeable acceleration in economic growth (which is actually the real Revolution). In the same way, we talk about the "Second Industrial Revolution" or the "Third Industrial Revolution" because these are convenient labels to describe how economic growth relied on different innovations (i.e., chemistry) and occurred in different countries (i.e., Germany, United States). But from a quantitative perspective, there is no discontinuity: economic growth just continued to increase.

The most important lesson from this graph is that verbal labels such as the "Industrial Revolution" are great to raise awareness about a phenomenon (the scale of the acceleration of technological and economic production), but misleading when it comes to understanding it. Such verbal labels tend to dichotomize the world (i.e., industrial/pre-industrial) when in reality all changes are continuous (i.e., more or less technology, lower or higher income). This does not mean that there is nothing to be explained. The exponential nature of the rise in innovativeness and the "Great Enrichment" still requires an explanation. But we should not assume that the Industrial Revolution was an "event" or even a "short period." It is rather part of a very general process of acceleration of cultural evolution, which is the phenomenon that requires an explanation: What made people more innovative? Was it institutions, natural resources, higher returns from investment in human capital (as advocated by Unified Growth Theory), new ideas, new genes (or higher frequencies of some alleles), or, as I have argued, increasing living standards and "slower" life history strategies? To answer this question, we first need more data, especially on innovativeness.

R1.1 More data on innovativeness

Many commentators have pointed out that the Life History Theory approach predicts that the Industrial Revolution should have developed not only in England, but also in other affluent countries, and in particular in Holland (**Allard & Marie**; **Allen**; **Artige, Lubart, & van Neuss** [**Artige et al.**]; **Hewson**; **Seabright**; **Stephenson**; **Tainter & Taylor**; **Tasic & Buturovic**). "If a 'psychology of affluence' developed in Great Britain, one would also expect it to have developed in Holland and to have brought about similar consequences" (Allard & Marie, para. 4).

I totally agree with the commentators: Life History Theory predicts that the richer a country is, the more innovative its people should be, and therefore, The Netherlands should have been more innovative during their Golden Age (seventeenth century) than other European countries and even more so than the English during the eighteenth century (for it is only in 1800 that England's gross domestic product [GDP] per capita reached the level reached by Holland in 1650).

Is it the case? Here, I think that we might again be victims of the paucity of quantification in the field. With Benoit du Buisson de Courson, we thus tried to quantify innovation during the early modern period across Europe (Baumard et al. 2019). We focused on scientific discoveries and scientists, which are better documented than technological inventions and innovators (for databases of English innovators during the eighteenth and nineteenth centuries, see Allen 2009b; Howes 2016a; Meisenzahl & Mokyr 2012). Scientific and technological innovation are of course different in important ways, and many technological innovations did not directly rely on scientific innovations. Yet, quantifying scientific innovations still allows us to test the theory that richer countries should be more innovative.

We gathered all scientists from the period 1500–1850. We included all individuals that are classified as scientists in Wikipedia: mathematicians, astronomers, physicists, biologists, chemists, botanists, entomologists, zoologists, geographers, and cartographers. Importantly, data sets such as Wikipedia convey an inherent estimate of the importance of an innovation: the more numerous the productions of an individual, or the more important they were, and the bigger the biography.

We collected three proxies of the importance of an individual (Gergaud et al. 2017): (1) length (number of bites in the Wikipedia page; (2) languages (number of languages into which the page is translated); (3) quotations (number of pages in Wikipedia containing a link toward this page). None of these indexes is perfect, and all have their biases, so we *z*-scored them and combine all three to create a more general index. To prevent a possible "linguistic bias" in favor of England, we ran this analysis in the three largest Wikipedias (English, German, and French) (see target article for more detail).

Our results are in line with modern accounts of the Scientific Revolution (Rossi 2001; Wootton 2015), with Italy and Germany leading in the sixteenth century, England and France during the seventeenth century (the century of the Scientific Revolution), and England, France, and Germany eventually taking the lead.

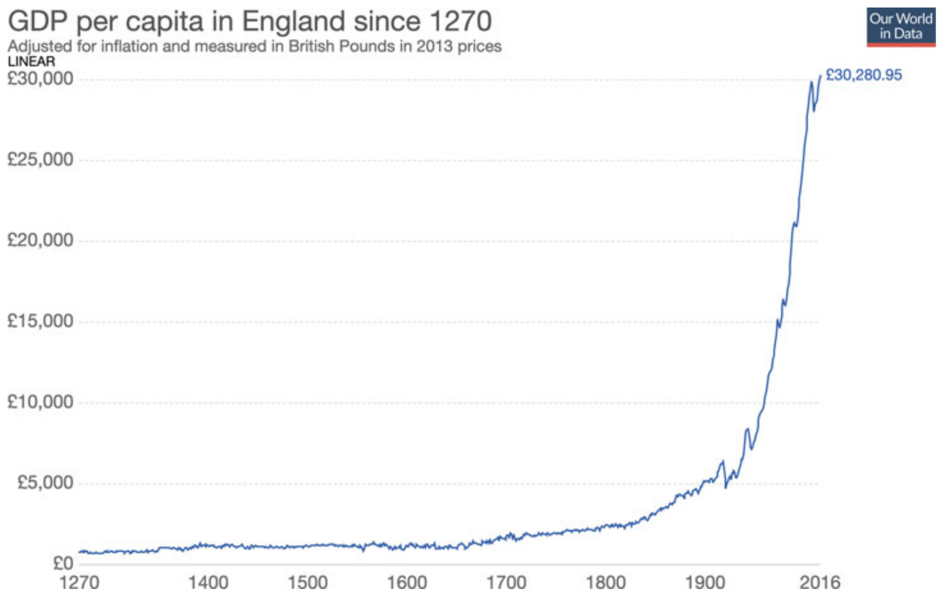

Figure R1. Gross domestic product per capita in England since 1270. Reproduced, with permission from Broadberry et al. (2015) via Bank of England (2017). Note that data refer to England until 1700 and the United Kingdom from then onward. OurWorldInData.org/economic-growth • Creative Commons BY license (open access).

We then built an index of "scientific domestic product" per capita. Per capita estimates are crucial to estimate the innovativeness of the respective European countries. For example, we tend to consider that, in the modern period, Italy (with Galileo and Torricelli), England (with Newton and Boyle), and France (with Pascal and Descartes) were more or less equally productive scientifically. But this assessment neglects the fact that, in 1650, France had 16 million people, Italy 12 million, and England only 3 million. In other words, for England to contribute as much to the Scientific Revolution, it must have been much more productive than France or Italy.

In line with the Life History Theory approach, people in Holland were more innovative than any other Europeans during its Golden Age (Fig. R2) and were also more innovative than the English during most of the eighteenth century, in line with the fact that seventeenth-century Holland was more affluent than eighteenth-century England. So, did the "psychology of affluence" develop in seventeenth-century Holland? Yes, it did, and to the same extent as in England a century later.

Commentators also asked why the Industrial Revolution did not take place in eighteenth-century Holland, still the richest country in the world. "Eighteenth-century England was not alone in having a high income. The Netherlands was the richest economy of the day, but the Industrial Revolution passed it by. Why?" (**Allen**, para. 8). Here, it is important to note that I place much emphasis on absolute income in the target article but the empirical literature is very clear about the fact that what matters is not only high income, but also sustained and predictable income (I return to this issue in sect. R2.5 when discussing the respective role of poverty, unpredictability, and inequality). In fact, despite its affluence, eighteenth-century Holland was in a drastically different situation than eighteenth-century England. From 1650 on, Holland indeed experienced an important economic crisis, with a 30% decline in urbanization rates and a 20% decline of GDP per capita. This economic decline must have affected psychological preferences in eighteenth-century Holland. The clear association between economic decline and scientific decline confirms this idea. Note that a similar phenomenon occurred in Italy and Belgium (high but decreasing income in the sixteenth and seventeenth centuries, accompanied by very low scientific innovation rates).

Such a graph also allows us to tackle the issue of population size (raised by **Allard & Marie**). At first sight, scientific production appears to be associated with population size because bigger and relatively more affluent countries such as England, Italy, and France provided many of the most famous scientists. Yet, in reality, per capita analyses reveal that bigger countries (Spain, Italy, Russia) are often less productive than smaller ones, such as Holland, Denmark, and Switzerland (not to mention China or India in the same period).

These quantitative analyses also help address the second aspect of the "why not Holland?" question, which is about the timing of the Industrial Revolution. Why not before? Why not in seventeenth-century Holland if seventeenth-century Holland was as rich as eighteenth-century England? These graphs suggest that this question is an artifact of the approach based on verbal labels. If the question becomes "Did seventeenth-century Holland experience the same level of innovation as eighteenth century England?" then, based on our study, the answer is probably "yes." The reason we have the impression that Holland is a counterexample is that the Industrial Revolution is associated with the steam engine or the spinning jenny. But if we adopt a more quantitative approach and define the Industrial Revolution as the acceleration of technological innovation and economic growth, then seventeenth century stops being a counterexample. In the seventeenth century, there was an acceleration of scientific innovations (in proportion to the level of economic development), and it was higher in more affluent countries.

I acknowledge that science is not technology, and may not be representative of innovativeness. To address this, Benoit de Courson and I leveraged Wikipedia to build a general indicator of innovativeness using all creative professions such as scientist, but also composer, writer, painter, sculptor, and philosopher. Our database includes more than 30,000 people and allowed us to create a "creative domestic product" per capita. This index shows, again, that the most prosperous countries are the more innovative. In fact, there is a strong correlation between GDP per capita and innovativeness in every domain ($r = 0.555$, $p < 0.001$).

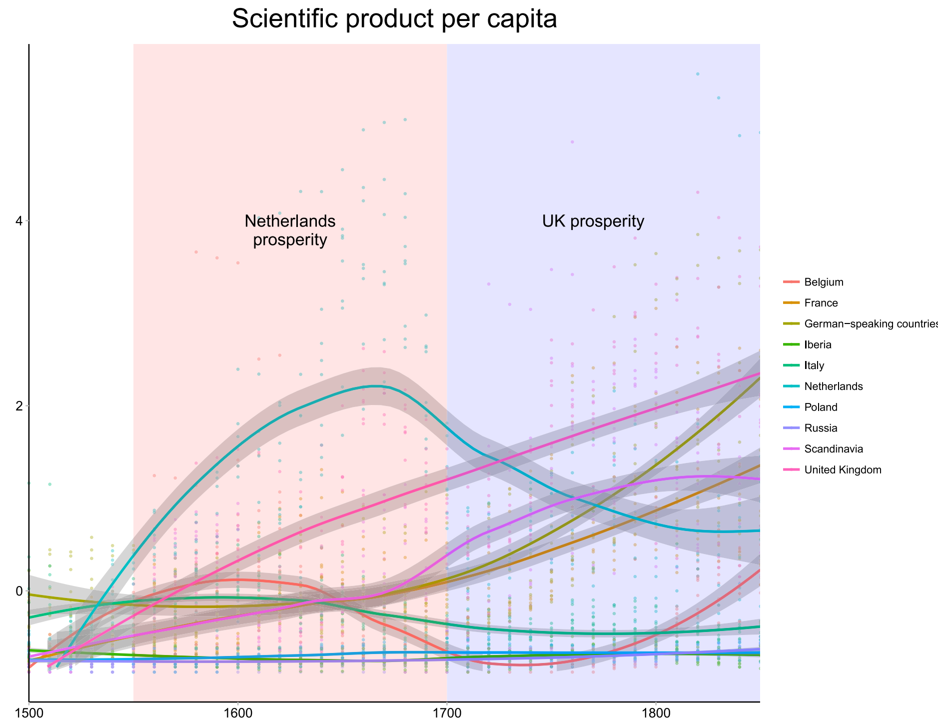

Figure R2. Scientific production per capita. The period of high income (>$1500) and growth in gross domestic product per capita rate is in pink for The Netherlands and blue for the United Kingdom. Countries with very low scientific production (Spain, Portugal, Poland, Russia) are omitted.

Such correlations, of course, cannot establish the causal relationship between living standards and innovativeness or rule out many possible confounding factors. For instance, **Artige et al.** suggested that printing may have played a role in increasing innovativeness and sparking the Scientific Revolution (Eisenstein 1980; Febvre & Martin 1997; Wootton 2015). Interestingly, the increase in scientific productivity indeed coincides with the invention and diffusion of printing in Europe. However, it is worth noting that the asymmetry of growth in scientific productivity in morthern and southern Europe suggests that its role was relatively minor in the Scientific Revolution. Scientific productivity in the less dynamic parts of Europe (Italy, Spain, Portugal, southern France) indeed does not seem to have been boosted by the invention of printing, despite its widespread use (e.g., Venice built its first press in 1469 and had 417 printers in 1500). Similarly, the diffusion of printed books in China from the ninth century onward did not drastically change the course of scientific productivity in China (Xu 2017). The same point has been made for the Ottoman Empire (Coşgel et al. 2012). These divergence points may suggest that printing is perhaps not an exogenous invention but rather an endogenous output of a particular society. Specifically, variations in printing usage suggest that printing increases scientific production only in places where people are already innovative.

R1.2. More data on the origins of the variability of economic development

In the target article, I discuss in detail the consequences of the affluence of England on the psychological preference of the English people. However, as pointed out by **Seabright**; **Tainter & Taylor**; and **Tasic & Buturovic**, I do not discuss the origins of England's higher level of affluence. Although I agree that this question is fascinating, it is beyond the scope of the article, which tackles the Great Enrichment (the acceleration of innovation) rather than the Great Divergence. Many works have already shown how early geographical advantages accumulate over the long run and can ultimately explain the divergent growth rates of modern nations (Abramson & Boix 2014; Chanda & Putterman 2007; Comin et al. 2010; Diamond 2011; Easterly & Levine 2003; Olsson & Hibbs 2005). In a recent paper, for example, Henderson et al. (2017) showed that nearly half of the variation in economic activity today can be explained by a parsimonious set of physical geography attributes (prevalence of malaria, ruggedness, temperature, precipitation, length of growing period, elevation, latitude, access to water transport, etc.).

It is important, however, to point out that these works focus mainly on explaining the overall advantage of Eurasia rather than the particular case of northwestern Europe. However, as I alluded to in the target article, some studies have pointed out that northwestern Europe might also have benefited from a number of geographical advantages during the late medieval and early modern periods: suitability for the use of the heavy plow (Andersen et al. 2016), suitability for the cultivation of the potato (Nunn & Qian 2011), or a better response to climate change (Pei et al. 2016). But more work is needed obviously.

R1.3. More data on living standards

An important part of the article is based on the fact that the most innovative countries, and especially England, were richer during the Industrial Revolution. Several commentators (**Artige et al.**; **Seabright**; **Stephenson**; **Tainter & Taylor**) expressed their skepticism about England's level of affluence and I fully agree that more data on living standards would be enormously useful to social scientists. Yet, it is worth highlighting that the available data do not contradict the picture presented in this review. Tainter & Taylor rightly point out that it would be problematic for the theory if data revealed that other countries experienced affluence levels comparable to those of eighteenth-century England. But to the best of our knowledge, no indicator (urbanization, GDP, or literacy) suggests that medieval Italy or medieval

England experienced a level of development comparable to that of eighteenth-century England. Similarly, we are not aware of any quantitative indicators suggesting that, as **Seabright** writes, "The French upper classes were probably more affluent than their English counterparts in the sixteenth through eighteenth centuries" (para. 7) (but I shall return to the question of France's living standards in sect. R2.5, for although the French upper class was probably poorer than the English upper class, lower inequality levels may have made the French lower class better off than their English counterpart).

In the same way, **Artige et al.** raise the very interesting question of China, which I only briefly discuss in the target article (para. 5): "Why did the Industrial Revolution occur in eighteenth-century England, and not earlier in Song China or Renaissance Italy?" Marco Polo indeed provided vivid reports about the wealth of Song China, and these testimonies have had a lasting impact on our collective representation of medieval China. As rich as these testimonies are, however, recent quantitative findings suggest that by 1300, urbanization and GDP per capita in Europe and China were already on par (Bosker et al. 2013; Broadberry et al. 2018; Xu et al. 2015). In 1500, Europe was producing 1113 books per inhabitant, whereas China's production per capita was only 19 (Baten & Van Zanden 2008; Xu 2017), and other indicators such as the number of book titles per capita also suggest that China was lagging behind Europe as soon as 1200 (Chaney 2018). Obviously, quantitative indicators are scarce before 1800. However, most of them point toward a higher level of development in the West, from the size of the largest libraries (Huff 2017, p. 320), to the monetization of the economy (Scheidel 2008), to the average duration of rulers (Chaney 2018), or to the development of useful knowledge (Cohen 2012; Deng 2010; Huff 2017; Mokyr 2016). On the other hand, it must be noted that China has been ahead of most non-European countries in terms of human development since the nineteenth century. Contrary to **Tasic & Buturovic**, its current level of economic growth (compared with other middle-income countries) is thus not surprising. What was surprising is rather the long communist stagnation.

Seabright suspects that I am cherrypicking the data on violence and literacy and that "if cathedral building had appeared to favor the Baumard hypothesis, it would have been cited, but because it does not, it was not" (para. 5). No one can of course can claim to have a fully exhaustive take on the wealth of available literature and data, but all the evidence I reviewed on living standards during the eighteenth century is reported in the target article, and although I am aware of fascinating archeological data quantifying ancient Roman and Greek living standards using shipwrecks, water-lifting devices, fish-salting vat capacity, building inscription, and size of churches (Bowman & Wilson 2009; Jongman 2014; Morris 2013), similar data seem harder to find for the medieval period (although see Blaydes and Paik [2016] for the study of cathedral building and economic performance in twelfth-century Europe). Like Seabright and many other social scientists, I would be keen to have access to similar quantitative indicators for the early modern period (see, e.g., Van Bavel et al. 2018 on the use of mills, cranes, and other immovable capital goods to quantify economic activity during the medieval period).

To sum up, the extant available data are coherent with the picture described in the target article. I do, however, share the commentators' excitement to have access to additional data. Specifically, more data are needed if we want to test further the causal relationship between living standards and life history strategies (see sect. R3.3). One way to complement economic proxies, for example, would be to study well-being and happiness. As **Huntsinger & Raoul** note, "People are generally happier when their basic material needs are met" (Diener 2012)" (para. 1). Moreover, "Citizens of richer countries, for example, experience greater subjective well-being and happiness than those of poorer countries. Looking within countries this research reveals that richer citizens are happier than poorer citizens (Sacks et al. 2010)" (para. 2). More critically, perhaps, is longitudinal research showing that as living conditions (e.g., economic and income growth) improve within a country, subjective well-being of its citizens also improves (Sacks et al. 2010; Veenhoven & Vergunst 2014)."

It will probably be difficult to quantify happiness throughout history, but some existing studies have put forward interesting attempts. For example, Oishi et al. (2013) coded State of the Union addresses given by U.S. presidents from 1790 to 2010 and showed that happiness evolved from being presented as good luck and favorable external conditions to being presented as favorable internal feeling states.

R1.4 More data on psychological preferences

Although historians of mentalities and emotions have long documented massive changes in psychological preferences regarding children (Aries 1965), love (Duby 1988), or violence (Elias 1982), quantitative series are scarce if not nonexistent, so the quest for quantitative indicators in this research area is of great importance **(Allen**; **Cowles & Kreiner**; **Haushofer**; **Huntsinger & Raoul**; **Olivola, Moata, & Preis** [**Olivola et al.**]; **Stephenson).**

In their commentary, **Olivola et al.** rightly point out that there are now innovative ways to track the evolution of psychological preferences. Specifically, "researchers can now use search engine data to map human behaviors and derive proxies of human cognition at the aggregate level" (para. 1). They take the example of time perspectives (specifically, they used Google Trends to calculate the relative volume of searches for future years, e.g., searching for "2020" in the year 2019), past years (e.g., searching for "2018" in the year 2019), and present years (e.g., searching for "2019" in 2019), within each country. Interestingly, they note that, in line with the Life History Theory approach, these time perspective indices are strongly correlated with per capita GDP (pc-GDP). Surprisingly, however, Olivola et al. find that richer people are more likely to search both for future years and for past years. This seemingly counterintuitive result may be the consequence of poor ecological validity (or of the fact that the slow end of the continuum is associated both with increased future orientation and with increased inward looking and curiosity, irrespective of time).

To take another example, cultural evolution studies in literature have revealed a decline in the proportion of positive emotion-related words over the last two centuries (Morin & Acerbi 2017). If one assumes that well-being and happiness are correlated and that better living standards increase well-being, the decrease in positive-related words in literary fiction raises a contradiction that has yet to be resolved. A similar remark can be made about the "optimistic language" built by **Varnum and Grossmann**. I agree with them that optimism is characteristics of a slow life history, but whether or not we are adequately capturing optimism when counting optimistic words is not fully clear.

One way to tackle this difficulty would be to use more ecologically valid indicators. With Lou Safra, Coralie Chevallier, and Julie Grèzes we have sought to apply novel methods to extract quantitative information from social cues in portraits, which are particularly promising cultural artifacts to document and quantify the level of trust over time (Safra et al. 2019). Experimental works have indeed revealed that specific facial features, such as a smiling mouth or wider eyes, are consistently recognized as cues of trustworthiness across individuals and cultures (Bente et al. 2014; Birkás et al. 2014; Engell et al. 2007; Todorov et al. 2015; Walker et al. 2011; Xu et al. 2012). We capitalize on this large empirical literature to build an algorithm that estimates trustworthiness based on a pre-identified set of facial characteristics (Sofer et al. 2017). Our results indicate that trustworthiness in portraits increased over the period 1500–2000, paralleling the decline of interpersonal violence and the rise of democratic values observed in Western Europe. Time-lag analyses further reveal that the increase in living standards predates, rather than follows, the increase in trustworthiness displays.

R2. More models are needed

R2.1. The role of resources (rather than mortality) in Life History Theory

Several commentators **(Blute; Tasic & Butruvic; Woodley of Menie, Figueredo, Aurelio & Sarraf** [**Woodley of Menie et al.**]) discussed the relationship between Life History Theory and cultural evolution. One important point, noted by Blute, is that Life History Theory must be distinguished from the *r*/*K* theory, which focuses mostly on density-dependent selection. Another important point is that standard Life History Theory aims to explain patterns of growth and reproduction in terms of fitness maximization in a given ecological context (Promislow & Harvey 1990; Stearns 1992). This body of work has focused on the effect of age-specific mortality and has inspired a lot of research in human behavioral literature (Nettle 2009b).

By contrast, this article departs from this tradition in the sense that it does not posit that mortality rate is the crucial factor accounting for behavioral differences within the human species. First, mortality did not change very much before the advent of scientific medicine in the early twentieth century. Second, and more importantly, even large changes in mortality are unlikely to explain the kind of behavioral variations described in the target article.

Consider, for instance, Bateson et al.'s (2015) study of impulsive decision making in starlings: Birds showing greater telomere attrition (an integrative marker of a poor biological state) were found to favor sooner-smaller rewards (one pellet of food in 1 second) more than larger-later ones (five pellets in *x* seconds). An interpretation of these results based on differential mortality risks would be as follows: Starlings in a poorer biological state have a greater probability of dying before collecting delayed rewards and should therefore favor short-term benefits. However, this interpretation is unlikely because dying during a choice experiment that does not exceed a few minutes is an extremely unlikely event, even for birds in poor states (Mell et al. 2017a). As in the starling example above, average differences in mortality (in years) are unlikely to account for specific discount rates when rewards are delayed over short periods (e.g., weeks, months, or even a few years).

This point is well illustrated by Riis-Vestergaard and Haushofer (2017) in their response to Pepper and Nettle's paper on the Behavioral Constellation of Poverty:

> People discount 46% over one year in Wang et al. (2016) – that is, they are indifferent between receiving a payment of \$x one year from today and \$x * 0.46 today, which translates into a required interest rate of more than 116%. However, average mortality risk over one year in the countries in this dataset is only 0.148%; thus, if the risk of dying before a future payment were realized were the only factor influencing discounting, people would be indifferent between receiving \$x in one year and \$x ∗ 1/(1 + 0.00148) = \$x ∗ 0.999 today. Mortality risk can therefore only account for 0.13% of the observed discounting. To produce discounting on the order of magnitude observed in the data, people would have to misestimate the prevailing mortality risk by a factor of 769. Thus, even if mortality rates partially explain the behavioral constellation of deprivation, it seems unlikely that it is the most important explanatory factor. (Riis-Vestergaard & Haushofer 2017, pp. 39–40)

In the target article, I thus rather focus on the effect of resources on life history strategies. To date, few formal treatments have been proposed to integrate the effect of resources in Life History Theory approaches (but see Mell 2018; Mell et al. 2017a). But the basic mechanism is very intuitive and is related to the pyramid of needs (Kenrick et al. 2010; Maslow 1943). The idea is that not all somatic investments have the same return rate and that the return rate of each investment depends on the somatic state of the individual and his or her stage of development. For an individual in a poor somatic state, investing in repairing the body is the most profitable investment. By contrast, for an individual in a good somatic state, investing in learning (rather than boosting the immune system one more time) is the most profitable investment. Thus, depending on where an individual is in the pyramid on needs, he or she will not have the same behavioral strategy. A range of studies indeed confirm that resources alone can explain massive behavioral difference between individuals, between social classes, and between societies (Inglehart 2018; Jacquet et al. 2019; Mell et al. 2017b; Safra et al. 2017)

R2.2. Life History Theory and innovativeness

In the target article, I defended the idea that higher levels of resources should increase innovativeness. Although they agree with this prediction, several commentators **(Boudesseul & Rubiños**; **Greenbaum, Fogarty, Colleran, Berger-Tal, Kolodny, & Creanza** [**Greenbaum et al.**]; **Woodley of Menie et al.)** put forward the idea that increased harshness should also increase innovativeness. Using optimal foraging theory, Greenbaum et al. contend that "risk-taking, explorative, and innovative behaviors are to be expected in stressed and subordinate individuals with less access to resources, because it is those individuals that must be creative to increase their fitness" (para. 2).

I agree that this is possible and very compatible with the theory put forward in the target article, especially because, as **Greenbaum et al.** point out, increased harshness and increased affluence "should be expected to correlate with different types of innovations" (para. 2), a point also raised by **Woodley of Menie et al.** but with a different perspective. Specifically, harshness should lead to "goal-oriented, short-time-scale problem-solving behavior, which involves modest risks and payoffs that can be clearly stated or conceptualized" (Greenbaum et al., para. 3), whereas affluence should lead to "creative behavior that is directed toward more open-ended problems, where the payoffs are more abstract, and not easily defined *a priori*" (Greenbaum et al., para. 3), that is, the kind of macro-innovations typical of the Industrial Revolution.

R2.3. Which proximate mechanism was involved in the Industrial Revolution: Optimism, happiness, trust, or intelligence?

In the target article, I listed several psychological changes that might have played a role in the Industrial Revolution: time discounting, optimism, intrinsic motivation, and trust. **Van der linden & Borsboom** add to this list that increased intelligence may also have played a role because a large empirical literature has found "a robust association between affluence and cognitive ability, which is likely to be at least partly causal in nature." As they note, this is totally compatible with the Life History Theory approach because a slower strategy is associated with higher somatic investment. I totally agree with them. An increase in intelligence may not explain the whole constellation of affluence (e.g., increase in trust, optimism, romantic love), but it is undeniable that it must have played a role in the rise of innovativeness and that I should have included it in the target article. In the same way, **Huntsinger & Raoul** put forward the idea that happiness and well-being may have played a role in the explosion of innovation because higher happiness is associated with higher creativity. From an evolutionary perspective, the function of happiness and subjective well-being is to "signal progress toward adaptive goals" (Kenrick & Krems 2018). More work is thus needed to identify the range of proximate mechanisms involved in increased innovativeness.

R2.4. The behavioral constellation of affluence and its role in cultural evolution

As emphasized in the target article, innovation is only one aspect of a larger "behavioral constellation of affluence." Increased access to resources has many effects on human psychology. Historically, the increase of resources is thus likely to explain not only the Industrial Revolution, but also the Age of the Enlightenment, the Scientific Revolution, the decline of violence, the decline of religion, the rise of democracy, and the demographic transition (about this last point, see also sect. R2.5). **Hewson** add to this list the rise of the bureaucratic state (what Douglas Allen [2011] has called the "Institutional Revolution"), noting that "an effective state depends above all on the cooperativeness of the elite, willing to put aside factional interests, willing also to exercise restraint in not dominating the non-elite" (para. 7). Hewson also adds to this list the European Marriage Pattern (nuclear family, late marriage), a late medieval phenomenon that "requires some degree of slow life history because it means deferring marriage and investing in cooperating with non-kin, which has a less immediate but better long-term pay-off than cooperation with kin" (para. 5).

Thus, there is (if the reader grants me one more constellation) a "behavioral constellation of modernity." This is, I believe, one of the strengths of the Life History approach. As **Hewson** writes: "These indications point to life history theory as a relatively parsimonious way to reconcile several bodies of evidence and lines of explanation into a coherent general account of the roots of economic modernity – a great reconciliation about the great enrichment" (para. 1). In fact, social surveys on modern populations show that there is a cluster of modern values: democracy, tolerance, secularization, social justice, et cetera. (Inglehart 2018).

The multiple aspects of the "behavioral constellation of modernity" have far-reaching consequences for our understanding of cultural evolution (Baumard 2017). Cultural norms (e.g., feudalism, Christianity, courtly ethos) are often presented as the ultimate triggers of the rise of modernity but they could very well be the consequence of a general change in people's psychology. Consider, for instance, North's famous thesis that the rise of the West was caused by institutional changes and a better protection of property rights, which are themselves presented as the product of some lucky circumstances (Acemoglu & Robinson 2012). However, as **Artige et al.** rightly point out, institutional changes might well be the product of rising affluence. (A very similar point can be made about **Atran**'s proposal that England had an especially liberal culture.) If resources can trigger changes in individuals' psychology and ultimately changes in values such as authoritarianism, trust, and optimism, then any cultural change can in principle be explained as the result of a psychological change or "evoked culture" (Tooby & Cosmides 1995).

In the same way, **Dutra** proposes that "cultural interconnectedness and in-group cooperation" may be at the origin of changes in the psychology of English people and of their innovative behavior. But, again, "cultural interconnectedness and in-group cooperation" could well be the product (rather than the cause) of affluence. Dutra explains England's higher cultural interconnectedness by its history of exploration, commercial expansion, and military colonialism (a related point also discussed by **Cowles & Kreiner,** as well as **Luoto, Rantala, & Krams (Luoto et al.**). However, as **Tasic & Buturovic** note, "LHT may be able to explain the settling of America, as the settlers exhibited precisely the initiative, optimism, and long-term horizon that Baumard argues was crucial for the enrichment of England" (para. 2). (In addition, not all maritime nations were ultimately successful, as the examples of Portugal, Spain, or even France attest). Of course, more work needs to be done to disentangle the various causal channels behind the rise of innovativeness (see sect. R3), but it is important to keep in mind that cultural values should not be considered as ultimate causes.

At this point, skeptics may wonder whether everything can be considered a part of the "behavioral constellation of affluence." In response to this, it is important to emphasize that the constellation has clear boundaries, and each of its elements has a predictable direction: more cooperation, not less; more exploration, not less; more patience, not less. Did England (and Europe) fit this description? In their commentary **Cowles and Kreiner** point out that England, and Europe in general, displayed very high levels of violence during the early modern period (a point also noted by **Dutra** and **Atran**). This, as well as the religious wars and the rise of absolutism, does not fit the constellation. And indeed, in absolute terms, it is undeniable that early modern Europe was violent, intolerant, racist, and sexist. But the more interesting question is relative: Was early modern Europe (or England) more violent, intolerant, racist, and sexist relative to other pre-industrial societies? Do we have evidence that a psychological shift was operating and that people in the Middle Ages had a more tolerant psychology relative to their predecessors? Framed as such, the answer to the question is straightforward: Early modern Europe abolished slavery for the first time in history, religious tolerance increased, and democracy rose. In fact, even the "crusading ethics" brandished by Cowles and Kreiner needs to be considered in the context of medieval history. Unlike many wars in history, the Crusades were partly triggered by moral considerations (taking back the Holy Land) rather than by pure material or political considerations (although, of course, there were undeniable material and political considerations). One piece of clear evidence of the moral aspect of the Crusades is that many crusaders started the Crusades by giving away their wealth and by making penance for they thought that being morally clean would further their success in the Crusades (Blaydes & Paik 2016; Vauchez 1993). Moreover, thousands of middle- and lower-class people, including women and children, chose to join the movement and to sacrifice their well-being for what (they thought) was a noble cause. But the best response to Cowles and Kreiner is probably quantitative studies of violence showing a strong decrease in interpersonal violence from at least the late medieval period onward (Pinker 2011a; 2018). This illustrates the need for a quantitative approach in history, a point discussed in section R1.

R2.5. Which ultimate environmental changes triggered the Industrial Revolution: Increased affluence, increased material safety, or decreased inequality?

The target article reviews the broad correlation between higher living standards and higher innovativeness. But as **Chen & Han** note, "two fundamental dimensions of environmental risk have been identified as affecting life history outcomes: harshness and unpredictability" (para. 2). Harshness refers to the absolute level of resources, whereas unpredictability refers to the variability in the availability of resources. Thus, the correlation between higher living standards and higher innovativeness might be explained in two (not mutually incompatible) ways. First, richer people may be more innovative because they have more resources, money, or time to invest in exploration. Second, richer people may be more innovative because their higher level of resources makes their environment more predictable: They do not need to worry about tomorrow and they can afford to take more risks. Empirical studies have often focused on harshness, which is easier to measure, but it is possible that unpredictability has larger effects than absolute harshness (Jacquet et al. 2019).

The effect of unpredictability might explain the marginal role played by The Netherlands in the Industrial Revolution (and its massive decline in scientific innovativeness in Fig. R2, sect. R2.1). As **Allen** notes, "The Netherlands was the richest economy of the day, but the Industrial Revolution passed it by" (para. 8). However, as discussed in section R1, The Netherlands experienced an important recession during the eighteenth century. In other words, despite their high level of income, Dutch people lived in a very uncertain environment during this century. This could explain why they became much less innovative in the eighteenth century than the in seventeenth century. From an evolutionary and psychological points of view, being rich in a volatile (or, worse, in a declining) environment is different from being rich in a stable (or rising) environment, which also fits with **Chen and Han**'s commentary: Unpredictability seems to have important negative effects on innovativeness.

It is also worth noting that the effect of unpredictability is probably more important for lower-income social classes. Thus, the importance of environmental unpredictability for understanding the Industrial Revolution depends on which social class contributed most to the process of technological innovation. If technological innovation was the product of upper-class and upper-middle-class inventors, the so-called "upper-tail of human capital," then the role of affluence might have been more important than that of unpredictability. However, if innovation was the product of the "artisans and apprentices who tinkered" (**Stephenson**), then the role of unpredictability might have been more important.

How can we decide between these two scenarios? One possibility is to look at inequalities: All things being equal, the more unequal the society, the poorer the poor and the richer the rich. If what matters is the income of the upper class (the inventors), then inequality should not prevent the rise of innovativeness. On the contrary, if what matters is the basic income of all social classes (including the tinkerers), then inequality should hinder the rise of innovativeness. This comparison converges with many commentaries (**Artige et al.; Chen & Han; Seabright; Stephenson**) inquiring about the impact of inequality (rather than poverty) in explaining life history strategies: "Did their relative wealth matter? How does inequality impact on reward orientation, materialism, and cooperation? If innovators arose only in a particular class or group, then is the greater wealth of England necessary for the theory to hold?" (Stephenson, para. 3).

Data on inequalities are scarce (which is partly the reason I did not discuss this point in the target article). Yet, existing works all point toward a rise of inequalities in Western Europe during the early modern period (Alfani 2015; Alfani & Ammannati 2017; Alfani & Ryckbosch 2016). This could suggest that the income level of the upper class, rather than the income level of the whole population, was the driving factor. However, it should be noted that inequality is not synonymous with poverty: England could have been more unequal but because it is was also richer, the English lower class might still have been richer than lower classes in the rest of Europe.

Another possibility is to look at other cultural revolutions. Historians have long noticed that while England was pioneer in terms of technological innovation, France was a pioneer in the political and demographic domains, with the French Revolution and the decrease in childbirth (a point noted by **Hewson**). Just as the Industrial Revolution started in England and then spread to the rest of the world (starting first with the most developed countries), the democratic and the demographic revolutions started in France and spread to the rest of the world, starting again in the most developed countries.

The fact that France, a country that was less affluent than England, was nonetheless ahead of England politically and demographically has long puzzled historians and represents a genuine problem from an evolutionarily grounded theory of cultural change. From an evolutionary perspective indeed, the shift from high to low fertility should have first occurred in the most affluent country. In a recent article, Cummins (2013) argued that this can be explained by France's higher level of equality. At the aggregated level, England was indeed richer, but at the individual level, it is possible that the lower class was richer in France than in England. This possibility fits well with **Stephenson**'s recent research indicating that unskilled men in London may have been half as rich as what previous estimates suggested and that (as noted by **Seabright**) England was no better than poorer countries such as Germany and the Scandinavian nations in terms of average literacy.

What made France more equal in the modern period? First, serfdom had long disappeared by the eighteenth century, and most peasants owned some land, unlike in most other countries in Europe. Second, compared with England, the proportion of landowners was much higher in France than in England, even before the French Revolution (a point noted by **Atran**)

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(Chesnais 1992; Cummins 2013). Third, inequality kept decreasing in France in the nineteenth century (Morrisson & Snyder 2000) as a result of the abolishment of feudal rights and the abolishment of the dime (a tax that "disproportionately" affected the lower classes), the rise of urban wages, and most importantly the confiscation and selling of church properties. In 1830, roughly 63% of the population was represented by landowners and their families, whereas the comparable figure for Britain is 14% (Chesnais 1992; see also Piketty et al. 2006).

Studying fertility life histories and wealth at death in four rural villages in France during the period 1750–1850, Cummins (2013) first shows that wealthy household actually reduced their fertility first, in line with evolutionary theory. He then shows that where fertility is declining, economic inequality is lower than where fertility is high, which confirms the idea that France started the demographic transition because lower-class people were better off than in other countries. A recent study, again at the micro-level, complements the idea that the demographic transition was indeed led by better economic conditions. Using a unique, comprehensive household-level data set for a single French village from 1730 to 1895, Blanc and Wacziarg (2019) found that the rise of life expectancy (in the middle eighteenth century) preceded the fall of fertility by several decades, confirming the idea that the French demographic transition was led by an increase in living standards (Béaur 2017).

To sum up, these preliminary works raise the intriguing possibility that depending on the income distribution, increased affluence may produce different cultural changes: What would matter for the Industrial Revolution would be the living standards of the upper class, whereas what matters for the demographic, and (possibly) for the democratic, transition, would be everyone's living standards, including those of the lower classes. We probably need better models to understand why the effects of living standards vary across cultural domains (on the specific role of capital in cultural evolution, see André & Baumard 2019).

R3. More predictions and more statistical instruments

As **Seabright** noted, we are not short of theories on the Industrial Revolution. What we need is better predictions and better instruments to decide between these theories. In this section, I discuss in more details the difference between the Life History Theory approach and two alternatives: genetic selection (sect. R3.1) and rational choice (sect. R3.2). I then argue, in agreement with **Haushofer**, that natural experiments would be especially needed to decide between competing theories (sect. R3.3).

R3.1. Genetic selection or adaptive plasticity?

Several commentators (**Luoto et al., Woodley of Menie et al.)** have pointed out that genetic selection may explain the rise of the psychology of affluence. (**Tasic & Buturovic** seem to think that the Life History approach implies an episode of genetic selection in the eighteenth century. It does not.) As noted at the end of the target article, it is indeed quite likely that, since at least the Neolithic, psychological traits such as time discounting, cognitive exploration, cooperation, and IQ have been under selection. Thus, the question is not whether some genes related to innovation were under selection during the early modern period, but whether, as it has been proposed by Gregory Clark and by the proponents of the Unified Growth Theory, this episode of selection was strong enough to account for the increase in innovation.

It is hard to decide between genetic selection and adaptive plasticity because, at the behavioral level, they make essentially the same predictions: Individuals should have higher levels of exploration, cooperation, and long-term thinking in more affluent and more developed societies. The main difference probably concerns the rate of evolution. In particular, according to the Life History Theory approach, one or two generations might be enough to trigger the "psychology of affluence." This is essentially what the work of Ronald Ingelhart and his colleagues shows (Inglehart 2018; Inglehart & Welzel 2005): Using international surveys from the 1970s, they demonstrate that, with rising living standards, each generation is psychologically slower then the earlier generation, and that the differences between successive generations are massive, and may account for sudden cultural changes such as the 1968 protests and the rise of gay and women's rights. In his commentary, **Hewson** points that out oil-exporting countries seem to be a counterexample: despite their very high income, they are still very conservative. This is true indeed. Yet, international surveys show that the opinion of the younger generation, the one actually born in an affluent country, differs from that of older generations (Inglehart 2018), but because these countries are not democratic, these psychological changes may have remained hidden (Bursztyn et al. 2018)

Whatever the role of genetic selection, it is unlikely that very general factors such as climate and coldness explain why the Industrial Revolution occurred at a particular place and at a particular time. As **Luoto et al.** acknowledge, explaining the specific tide of events that led to the Industrial Revolution, climate is not specific enough to account for the timing and the location of the Industrial Revolution (on the limit of climatic explanation, see also Currie & Mace 2012; Mell et al. 2017b; Thornhill & Fincher 2013).

R3.2. Rational choice or adaptive plasticity?

The other important alternative to adaptive plasticity is rational choice theory. As many commentators (**Allard & Marie; Allen; Haushofer; Hirshleifer & Teoh; Seabright**) pointed out, the evidence offered in the target article is perfectly compatible with rational choice theory. As Hirshleifer & Teoh write:

> The evidence and arguments that Baumard brings to bear in support of this explanation for the Industrial Revolution do not uniquely distinguish it from plausible alternatives. A very simple one is that increased prosperity freed up more time for individuals to engage in innovative activity and increased the benefits from doing so. This possibility is consistent with the great bulk of the evidence adduced in support of the preference-shift explanation. (para. 1)

Some commentators (**Allen; Haushofer; Hirshleifer & Teoh; Seabright**) also point out that rational choice is more parsimonious than evolved plasticity as it required only the ability to respond to changes in costs and benefits (rather than the capacity to change psychological priorities).

I fully agree that these criticisms are warranted and tried to anticipate them in the target article (sect. 6.3) using two main arguments: (1) Life History Theory provides a better account of the "behavioral constellation of affluence," which is increased not only in innovativeness, but also in the rise of trust, romantic love, or empathy. (2) Life History Theory explains the rigidity of human psychology better, that is, the fact that some preferences are calibrated *in utero* or during childhood and does not seem to respond to changing costs and benefits later in life.

Hirshleifer & Teoh concede that Life History Theory explains the other parts of the constellation well. Yet, these behavioral changes may have played a relatively minor role in the Industrial Revolution. Furthermore, these changes could also result from pure rational reasons:

> For example, consider the shift of the English novel toward a focus on long-term planning. The only difference in our possible explanation for this shift from Baumard's is that this shift, instead of deriving from a shift in people's personalities, could derive from an incentive-induced shift in people's interest and attention toward long-term strategies. (para. 8)

As for the second argument (early calibration and rigidity), Hirshleifer & Teoh suggest that one way to tease apart the two theories would be to develop evidence about age-specific environmental shifts and their effects. Here, I think that the Life History approach is on better grounds because the work of Inglehart and his collaborators (Inglehart 2018; Inglehart & Welzel 2005) clearly show cohort effects: People living in the same country at the same time have different opinions depending on the year they were born in. Furthermore, people display a high level of rigidity: International surveys show that people's level of post-materialism does not evolve very much over their life course, despite a huge change in the environment (in particular in income level). Further works have shown long-lasting effects of traumatic (and exogeneous) events (Hörl et al. 2016).

Finally, it might be worth considering other cultural revolutions such as the demographic transition (see sect. R2.4). Unified Growth Theory, for example, explains the demographic transition as a response to industrialization and the increasing return of human capital (Galor 2011). The rising incentives to accumulate human capital modify the trade-off between the quantity and quality of children. Families respond (rationally) to these changes by reducing their number of children and by investing more in their education. By contrast, Life History Theory explains the demographic transition as phenotypic change in individual's strategy, triggered by the fall of mortality: Because children are less likely to die, individuals reduce their fertility and invest more in each child.

In their work on the French demographic transition, Blanc and Wacziarg (2019) found that the fall of fertility preceded the rise in education by several decades and did occur in the absence of industrialization (e.g., in the four villages studied, the share of the adult male population engaged in agriculture remained stable, at 67% from 1780 to 1800 and 69% from 1875 to 1895, and the small textile weaving industry declined from 11% to 5% of the adult male population during the same period). This suggests that, against Unified Growth Theory, the fall of fertility occurred in the absence of any change in the return of human capital. By contrast, the fall of fertility was preceded by the rise of life expectancy (in the middle eighteenth century), which corresponds to the prediction of the Life History Theory framework.

Beyond the case of the demographic transition, this debate illustrates the difference between rational choice theory and evolutionary theory: For the former, individuals respond to incentives in the environment, whereas for the latter, evolved mechanisms (that are not necessarily adapted to the current environment) respond to specific cues that were, on average, relevant in the environment of evolutionary adaptedness. Even if it is currently difficult to tease apart the predictions of the two frameworks, it is likely that ultimately, they will generate a range of diverging predictions.

R3.3. More natural experiments

Many commentators have pointed out the need to tease out causal effects from historical data (**Artige et al.**; **Dutra**; **Haushofer**; **Hewson**; **Kotchoubey**; **Seabright**; **Tasic & Buturovic**; **Varnum & Grossmann**), and I could not agree more. As shown by **Varnum & Grossmann**'s commentary, it is extremely difficult to statistically tease apart the direction of causality and the exact causal role of each factor. This is especially true for the Life History Theory framework because it predicts a cluster of psychological traits (see sect. R1.2). As Kotchoubey notes, "there is a uniform relation between affluence, innovation rate, quality of life, prosocial behavior, optimism, long-term investments (e.g., education), social trust, and several other variables, all being negatively correlated with violence and materialist views" (para. 1).

In response to this problem, the tradition in behavioral and brain sciences has been to build large, complex models that observe and model all confounders and to use methods such as Granger causality, Structural Equation Modelling, and Bayesian networks. All these methods assume that confounding is unlikely or impossible. Yet, as Marinescu et al. (2018) point out in a recent review paper, "unconfoundedness is rarely plausible as virtually all systems that we study have more variables of importance than we can realistically measure or model." The alternative is, as **Haushofer** suggests, using causal or quasi-causal methods and, in particular, natural experiments, such as Nunn & Wantchekon's (2011) famous paper on the impact of slavery on trust in Africa. The idea is to find variables in data sets that are assigned in a way that is as good as random and to use methods such as Regression Discontinuity Design, Difference-in-Differences approach, and Instrumental Variables. As Marinescu et al. note, these techniques are standard in economics yet are rarely used in many branches of behavioral and neuroscience research.

In the section entitled "Testing the Theory" (sect. 6.3) in the target article, I mention a working paper in collaboration with economists Elise Huillery and Leo Zabrocki, in which we use the introduction of the heavy plow as a causal instrument and exploit two sources of exogenous variation: variation over time arising from the adoption of the heavy plow on the one hand, and cross-sectional variation arising from differences in regional suitability for adopting the heavy plow on the other hand. We show that an exogenous income shock can explain the increase of some psychological preferences such as romantic attachment and attitudes regarding self-control (Baumard et al. 2018). Of course, our work does not deal with innovativeness in the early modern period, but it does provide an interesting example of the way in which predictions of the Life History Theory framework can be causally tested in history. Future work should aim to find natural experiments to test the causal role of affluence in explaining the rise of innovativeness in early modern England.

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[The letters "a" and "r" before author's initials stand for target article and response references, respectively]

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