Response to the Referee Report 2

by M. Aykut Attar

I thank the second referee for his/her detailed comments and nice words on my paper. The second referee raises important issues as well, and these issues could be addressed in a revised version. I provide below a discussion using the structure of the referee's report.

Main Concern

The model proposed by Strulik and Weisdorf (2008) ingeniously incorporates quasi-linear preferences towards consumption and fertility within a dual-economy framework where technological progress is due to learning-by-doing in both sectors. Their model, though it is indeed a simple one, successfully explains the transition to modern growth with the demographic transition (the hump-shaped pattern of population growth) and the structural transformation (the allocation of resources from agriculture to industry).

The model of my paper aims to enrich our understanding through the dual role of entrepreneur-inventor's for the growth of manufacturing productivity and the expansion of useful knowledge. Taking the entrepreneur-inventor as the main actor of the play is motivated by the prosopographical evidence of Meisenzahl and Mokyr (2012), and what motivates the focus on useful knowledge is Sullivan's (1989) conclusion that a supply-side factor should be responsible for the upward trend break in inventive activity in mid-1700s' England (see Section 1.2).

The central message of my paper is that, as the inventor is in the meantime the business owner, the industrial revolution starts only when the stock of useful knowledge gets large enough to make inventive activity optimal while the pace at which the economy approaches to its industrial revolution depends on the supply of entrepreneurship. Historical narratives of the Industrial Revolution strongly acknowledge these notions, but existing unified growth models, to the best of my knowledge, do not pay attention to this dual role of entrepreneur-inventor's.

As the first referee indicates in his/her report as well, the mechanism I am proposing as decisive for an industrial revolution to start might have been studied in a simpler way at the cost of remaining silent about demographic transition and structural transformation. But building upon Strulik and Weisdorf's (2008) framework allows us to see how the choice of fertility and the dynamics of the agricultural sector would affect the timing of the industrial revolution through the supply of entrepreneurship. This, I believe, is not a trivial point as the model's predictions are in complete accordance with the timing results obtained by Desmet and Parente (2012) and Peretto (2013).

Additional Concerns

1. *On the Regime Transitions.* Proposition 6 argues for a particular sequencing of regime transitions (1-2-3-4), and Remark 1 discusses the meaning and the empirical motivation behind the assumptions of Proposition 6. It might be true that the main text deserves a more detailed discussion of Proposition 6, but only the assumptions of Proposition 6 are needed to ensure the 1-2-3-4 sequencing.

   On the other hand, I realize now a confusion might arise regarding the additional assumption of $\hat{t}$ being not too large for the equilibrium path to look like as in Figure 3; the discussion in Footnote 11 may not be clear enough. In general, the convergence to Regime 4 through Regimes 2 and 3 can be of two types:

(a) The first one does not require $\hat{t}$ to be not too large, and the economy converges to the quasi-steady-state (of Proposition 3) in Regime 2 before the industrial revolution starts. In this scenario, fertility remains stable at its historical maximum after the convergence to the quasi-steady-state is completed. As discussed in Footnote 11, this is arguably consistent with the 20th century experience of today's least developed economies that remain agrarian but sustain an increasing level of population.

(b) The second configuration of the equilibrium path requires $\hat{t}$ to be not too large as we do not observe long episodes of fertility remaining stable at its historical maximum for early industrialized economies such as England and France.

2. *On the Role of Technological Progress in Agriculture.* The productivity growth in agriculture before the Industrial Revolution in England is associated with a (slowly) declining share of the agricultural sector (see, e.g., Clark, 2010). The model of my paper indeed indicates that, in Regime 1, the slowly growing agricultural productivity (X_{ft}) implies a slowly declining labor share of the agricultural sector (H_{ft}/N_t). On the other hand, once the economy enters Regime 2 with no invention, the labor share of the agricultural sector remains stable at a relatively high level until the economy enters Regime 3 at which inventive effort is positive. Considering the fast decline of the relative size of the agricultural sector after the Industrial Revolution, I think that the model's prediction overall is in line with Clark's (2010) data. While the referee is right in pointing out that these might have been explained in a clearer way, I respectfully disagree with the referee on the relationship between agricultural productivity and the inevitability of the industrial revolution: The industrial revolution in the model is inevitable because the stock of useful knowledge exhibits growth both in Regime 1 and in Regime 2.

3. *On the Boundary Constraint of* $n_t \geq 1$. Growiec (2007) shows in a generalized framework that strictly positive steady-state economic growth necessarily requires knife-edge assumptions. In the model of my paper, the boundary constraint of $n_t \geq 1$ serves exactly this purpose; economic growth is sustained in the long run without an explosive or an implosive level of population.[1] Strulik and Weisdorf's (2008) model converges to an asymptotic equilibrium without population growth and economic growth, and fertility could be below its replacement level before the convergence to the asymptotic equilibrium is completed. Therefore, no knife-edge assumption in the sense of Growiec (2007) is necessary.

   The main mechanisms my paper emphasizes may be preserved under alternative treatments of population growth. The simpler way is to model population growth in reduced-form as in, e.g., Parente and Prescott (2005) and Cavalcanti et al. (2007), where the law of motion for population satisfies $N_{t+1} = g(\bullet)N_t$ with a non-monotonic function $g(\bullet)$ of, say, GDP per capita. This would not change the main results of the paper. The other way that I have not attempted is to build on other mechanisms implying a stabilizing population in the long run. Peretto and Valente (2013), for

[1] Jones (2001) imposes a similar constraint with the same motivation where population growth decreases to zero and economic growth continues in the long run. Lagerlöf (2006), in the quantitative analysis of Galor and Weil's (2000) model, sets the parameter values so that population growth is zero in the long run. Again, for economic growth to continue in the long run, Desmet and Parente (2012) assume that the cost of reproduction increases with the population size.

instance, construct a model where the land constraint of the economy affects the cost of reproduction in such a way that the long-run level of population is fixed. I believe that considering the finiteness of resources as in Peretto and Valente (2013) is an interesting research avenue for the unified growth models.

4. *On the Scale and Fishing-Out Effects.* The arrival rate a_t, for any given level of research effort h_{rt}, increases with the stock K_t of useful knowledge through $a_t = \theta f(K_t) h_{rt}$, and K_t increases with the mass E_t of active entrepreneurs. The scale effect is actually imposed on the growth of K_t and not of $\bar{X}_t$.

   Returning to the fishing-out effect, this may be introduced in two ways:

   (a) As suggested by the referee, an upper bound may be imposed on the number of innovations. This can be done either through an upper bound $\bar{z}$ on the realized number z of inventions (with a right-truncated Poisson distribution) or through an upper bound $\bar{a}$ on the arrival rate a_t (with no change in the Poisson distribution).
   In both cases, the upper bounds may be increasing with K_t and, perhaps more appropriately, decreasing with $\bar{X}_t$.
   In the first case with a bound on z, Lemma 1 fails to obtain a simple form for the expected profit because of the right-truncated Poisson distribution.[2]
   In the case of $a \leq \bar{a}$, the closed-form solutions can still be obtained, and $a_t = \bar{a}$ could be optimal as long as we have $\bar{a} < a_t^{\max} = \theta f(K_t)$. If $\bar{a}$ is indeed a function of K_t and $\bar{X}_t$, the threshold level $\hat{K}$ would change in such a way that a higher initial level of $\bar{X}_t$ delays the industrial revolution. This is an interesting *technological lock-in* result that simply says that it takes more time for a more advanced preindustrial economy to start an industrial revolution.

   (b) A simpler way of introducing the fishing-out effect is to extend $f(K_t)$ into $f(K_t, \bar{X}_t)$ where $f_X(\bullet, \bullet)$ is negative so that the growth of $\bar{X}_t$ decreases the productivity of the research effort. Once again, there is technological lock-in since a higher $\bar{X}_0$ delays the industrial revolution.
   Notice that the threshold level of K_t would now be time-varying in Regimes 3 and 4 because it depends on $\bar{X}_t$. Let $\hat{K}_t$ denote this threshold. In general, the growth of $\bar{X}_t$ for periods satisfying $K_t > \hat{K}_t$ may eventually imply $K_{t_1} \leq \hat{K}_{t_1}$ at some $t_1 > t$ to stop the wheel of invention and fix $\bar{X}_t$ at $\bar{X}_{t_1}$. Then, it takes some number of periods for the growth of K_t to catch up with $\hat{K}_t = \hat{K}_{t_1}$, and the arrival rate a_t becomes positive again at some $t_2 > t_1$. In other words, there might be a "punctuated" equilibrium of $\bar{X}_t$ over alternating episodes of $a_t = 0$ and $a_t > 0$. I suppose, however, that the shape of the equilibrium path, once smoothed, would not be dramatically different.
   On the other hand, there may exist characterizations of $f(K_t, \bar{X}_t)$ that lead $\hat{K}_t$ to converge to a constant for some large $\bar{X}_t$. In such a case, the model tells a more involved story of technological progress in the long run: There exist episodes before the industrial revolution over which $\bar{X}_t$ grows and then stabilizes, and the industrial revolution now starts at the period where the fishing-out effect of $\bar{X}_t$ is no longer binding with $K_t > \hat{K}_t$. Mokyr (2002, Ch. 3), in fact, suggests such an

[2] The Poisson probability of realizing $z \leq \bar{z}$ inventions given the arrival rate $a \geq 0$ reads $(a^z/z!)/(\sum_{s=0}^{\bar{z}} a^s/s!)$.

interpretation: Before the times of the Industrial Revolution, the waves of invention were subject to diminishing returns because not enough was known about the natural phenomena underlying the production techniques.

5. *On the Discussion of Result 3.* How Result 3 is obtained is discussed in the first paragraph of Page 30, but this discussion needs to be extended and clarified with some formality. Specifically, it would be useful to recall the solutions of n_t and H_{ft}/N_t in the relevant regimes and to show how ϕ and $\bar{X}_0$ affect G_{Kt} in the claimed directions.

6. *On the Terminology of Discoveries vs. Useful Knowledge.* I agree with the referee on this point as well. K_t in the model represents all propositional forms of knowledge relevant to the production processes. Thus, the stock of useful knowledge actually covers more than the term *the stock of discoveries* might imply.

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