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Comment Samuel Kortum

Why don't we have better electric cars by now? Daron Acemoglu formalizes an argument that there are insufficient incentives to innovate on alternative technologies. Since a mass-market for electric cars has not yet arrived, an innovation today won't generate large current profit. Nor will it generate much future profit since, by the time the market gets big, another better innovation will likely have come along.

Yet, the innovation in electric car technology that might have been made today could have a high social value. It might have become a valuable technological step on the path to future improvements. The problem is that too few steps are taken early enough in this process of getting to a better electric car. Daron's chapter turns this interesting verbal story into a mathematical model.

I want to deal with two issues in this discussion. The first is about the economic forces at work in Daron's model. I try to highlight them by introducing a simpler formulation. The second is about the economic forces missing from Daron's model. Here, I simply speculate about how they could be brought into future work on this topic.

A Simplified Model

The model in Daron's chapter builds on Grossman and Helpman (1991) in which innovations form the rungs of a "quality ladder" for each intermediate good. The arrival of a new innovation is a step up the quality ladder, leading to the depreciation of the private value, but not the social value, of the innovation left below.

Daron adds a new dimension to the model. For each of the unit continuum of intermediate goods there is also an alternative technology, not yet used in production. With a hazard rate α, this alternative becomes the new mainstream technology. When it comes into play, the innovations forming the previous mainstream quality ladder become useless. This transition implies both a private and social depreciation of the advances embodied in the old quality ladder.

Churning over quality ladders means that some level of innovation is required just to prevent technological regress. While technology improves along a given quality ladder, at some point it all becomes obsolete as a whole new approach is pursued. The idea of alternative technological trajectories captures an important aspect of reality. Not all technology builds on what came before it. I suspect this idea will itself be something that future economic models build on.

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I thank Unnikrishnan Pillai for helpful comments.

In my stripped-down version of Daron's model, I consider a fixed arrival rate of innovations η and no aggregate technological progress. The steady-state equilibrium will feature a fixed fraction ω of research effort aimed at innovations in alternative technology and $1 - \omega$ devoted to innovations in the mainstream technology currently being used.

I follow Daron's formulation as closely as possible, but in one important respect I stick closer to Grossman and Helpman. In particular, I replace equation (3) in Daron's model with a Cobb-Douglas production function over the continuum of intermediates, so that the same amount is spent on each intermediate. Taking aggregate spending to be the numeraire, spending on each intermediate can be set to 1.

Each innovation improves the quality of an intermediate by the factor $1 + \lambda > 1$. While that innovation is in use, Bertrand competition leads to a profit flow to the innovator of $\pi = \lambda/(1 + \lambda)$, independent of the rung on the quality ladder. This profit flow comes to an end with the arrival of the next innovation on the quality ladder or with the arrival of the alternative quality ladder. The overall private obsolescence rate is therefore $\alpha + (1 - \omega)\eta$. With a discount rate r, the Bellman equation for the value V of an innovation currently in use is:

$$rV = \pi - [\alpha + (1 - \omega)\eta]V.$$

Note that this equation is nearly identical to equation (5) in the chapter, except that here we allow $\omega > 0$.

Suppose it is easier to innovate in the alternative technology. The innovation rate in alternative technologies is not $\omega\eta$ but rather $\omega\zeta\eta$, with $\zeta > 1$. Although this assumption is ad hoc, the idea is that there are more untapped opportunities in the alternative technology. The Bellman equation for the value V^A of an innovation on the alternative technology is thus:

$$rV^A = \alpha(V - V^A) - \varsigma\omega\eta V^A.$$

While there are no current returns, there is a chance of a capital gain $V - V^A$ when the alternative technology becomes mainstream. The assumption of $\zeta > 1$ gives a possible rationale for innovating in the alternative technology, since innovating there is easier. (With $\zeta \leq 1$ it would always be more profitable to innovate in the technology that is currently in use.)

Is it possible to have diversity in research ($0 < \omega < 1$), in this market equilibrium, with some innovation in the current technology and some in the alternative technology? We need ζ large enough to overcome the fact that an innovation in the alternative technology only generates revenue once it becomes the mainstream technology. Assuming $(\varsigma - 1)\alpha > r$ (i.e., for α or ζ large enough) we can solve for the allocation of research:

$$\omega = \frac{(\varsigma - 1)\alpha - r}{\varsigma\eta},$$

that is consistent with diversity; that is, $V = \varsigma V^A$.

The fraction of research devoted to alternative technologies is increasing in ζ and α while decreasing in r and η. There is an economic force lending stability to this equilibrium with diversity in research. All else equal, a higher ω would lead to more innovation on the alternative quality ladder, raising the obsolescence rate for any given innovation, and hence lowering the value of an innovation there. This equilibrating force is absent from the social planner's problem since the flow of social value, unlike the private value, is not destroyed by the arrival of the next innovation.

What are the welfare implications of this equilibrium? The flow of social surplus from an innovation in the mainstream technology is[1]

$$\pi^S = \ln(1 + \lambda) > \frac{\lambda}{1 - \lambda} = \pi.$$

Thus, the social value V^S of such an innovation solves:

$$rV^S = \pi^S - \alpha V^S.$$

Notice that the social value remains after the innovation is surpassed, but not after the quality ladder has become obsolete. The social value of an innovation in the alternative technology V^{AS} solves:

$$rV^{AS} = \alpha(V^S - V^{AS}).$$

For parameters that yield $\omega > 0$ in the market equilibrium, it is easy to show that

$$\varsigma V^{AS} > V^S.$$

The social planner would like to aim all research at the alternative technology, thus taking advantage of $\zeta > 1$ as long as α is large enough and r is small enough.

The social planner exploits the fact that it is easier to innovate in the alternative technology. Why not always innovate on the next big thing so that we are ready when it becomes mainstream? The planner therefore directs all researchers to the alternative technology. In the market equilibrium, on the other hand, research is split between alternative and mainstream technology. The bottom line of this simplified model, while not identical, is quite complementary to Daron's chapter. The market provides insufficient incentives for innovation in the alternative technology. The social planner would like to get a technologically advanced electric car sooner. On the other hand, the results on diversity are reversed from those in the chapter unless we redefine diversity to mean innovating on an alternative technology.

1. Notice that the demand curve for a single good is $q = 1/p$. Thus, the flow of social value of an innovation that lowers costs from c to $c' = c/(1 + \lambda)$ is

$$\pi^S = \int_{c'}^{c} (1/p)dp = \ln(c/c') = \ln(1 + \lambda).$$

What Is Missing?

There are several new economic forces at work in Daron's model. One is that innovations do not always improve on what came before. Occasionally we must scrap a whole line of technological advances in order to try something completely different. Another is that the divergence between the private and social returns to an innovation tilt the market away from innovation in a technology that is not currently in use. Finally, and related to the second, more innovation in a particular technology is itself a disincentive for research in that technology, since it leads to a shorter window in which to reap private returns. While the economic logic of this last effect is impeccable, one may question whether it captures an important force limiting actual research in alternative technologies.

I would conjecture, quite the opposite, that intensive research in alternative technology would tend to attract more researchers, at least up to a point. The reason is that these researchers would likely feed off each other through spillovers of knowledge and through advances in complementary technologies. For example, the reason we don't have a good electric car is likely because the battery technology is not very good. And, to make progress there you need a large talented group of researchers working on battery technology. These researchers would learn from each other, the innovations would come, and they would all make enough money to continue. In other words, the problem is not too much competition but lack of a critical mass.

Notice this logic is opposite to Daron's model. His model implies that with many people working on battery innovations, each innovation will make very little money since it will soon be surpassed by a better innovation from a competitor. But, maybe the more important force is the learning generated by that competition, with the net result that researchers are attracted by this competition. Of course, this line of argument is quite speculative. It is just another verbal story waiting to be properly formalized.

Reference

Grossman, Gene, and Elhanan Helpman. 1991. *Innovation and Growth in the Global Economy.* Cambridge, MA: MIT Press.