Numerical Example in economic Growth

Abstract

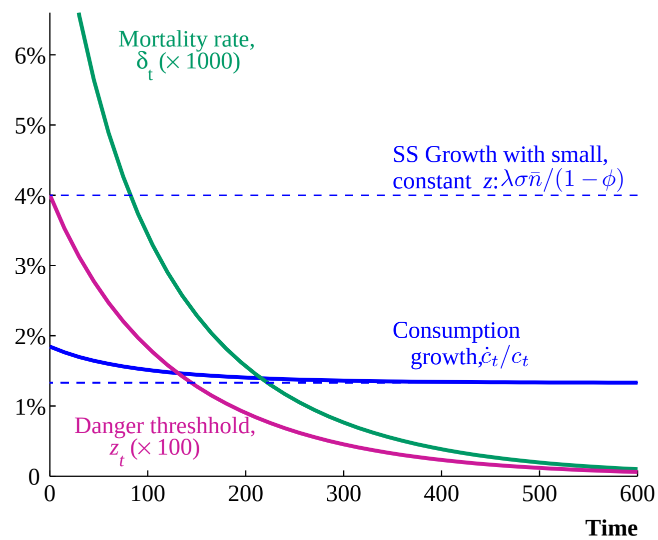
We now report a couple of numerical examples to illustrate how this economy behaves along the transition path. We make some attempt to choose plausible parameter values and to produce simulations that have a "realistic" look to them. However, the model abstracts from a number of important forces shaping economic growth and mortality, so the examples should not be taken too literally. Mainly, they will illustrate the extent to which growth can be slowed by concerns about the dangers of certain technologies.

The first example features sustained exponential growth ($\eta < \infty$). The second assumes a distribution $F(z)$ with an elasticity that rises to infinity as z falls to zero. According to Proposition 3, this example exhibits a growth rate that declines to zero, even though consumption itself rises indefinitely.

Benchmark Example

The basic parameterization of the benchmark case is described in Table 1. For the curvature of marginal utility, we choose $\gamma = 1.5$; large literatures on intertempo-

Figure 3: Equilibrium Dynamics: Benchmark Case



Note: Simulation results for the competitive equilibrium using the parameter values from Table 1. Consumption growth settles down to a constant positive rate, substantially lower than what is feasible. The danger threshold and mortality rate converge to zero.

ral choice (Hall 1988), asset pricing (Lucas 1994), and labor supply (Chetty 2006) suggest that this is a reasonable value. For $F(z)$, we assume an exponential distribution so that $\eta = 1$; we also assume this distribution has a mean of one. We set $\beta = .02$: government spending on ideas equals 2% of aggregate consumption. For the idea production function, we choose $\lambda = 1$ and $\phi = 1/2$, implying that in the absence of declines in z_t, the idea production function itself exhibits productivity growth. Finally, we assume a constant population growth rate of 1% per year. The other parameter values are relatively unimportant and are shown in the table. Other reasonable choices for parameter values will yield similar results qualitatively. The model is solved using a reverse shooting technique, discussed in more detail in Appendix B.

Figure 3 shows an example of the equilibrium dynamics that occur in this economy for the benchmark case. The economy features a steady-state growth rate of per capita consumption of 1.33%. This constant growth occurs while the danger threshold and the mortality rate decline exponentially to zero; both z_t and δ_t grow at -0.67%.

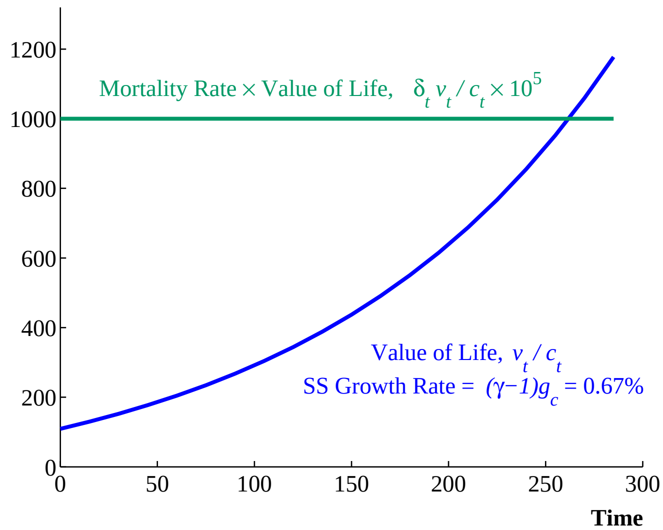
Several other features of the growth dynamics are worth noting. First, the particular initial conditions we've chosen have the growth rate of consumption declining along the transition path; a different choice could generate a rising growth rate, although declining growth appears to be more consistent with the value of life in the model (more on this below).

Second, consider total factor productivity for the idea production function. With $\lambda = 1$, TFP is $\alpha F(z_t)A_t^{\phi}$. Because we've assumed $\phi = 1/2$, this production function has the potential to exhibit positive TFP growth as knowledge spillovers rise over time. However, a declining danger threshold can offset this. In steady state, TFP growth for the idea production function is $\phi g_A + \eta g_z = -0.33\%$. That is, even though a given number of researchers are generating more and more candidate ideas over time, the number that get implemented is actually declining because of safety considerations.

Finally, the steady-state growth rate of 1.33% can be compared to an alternative path. It is feasible in this economy to let the technology-induced mortality rate fall to some arbitrarily low level — such as 1 death per billion people — and then to keep it constant at that rate forever by maintaining a constant technology cutoff $\bar{z}$. As this constant cutoff gets arbitrarily small, the steady state growth rate of the economy converges to $\lambda\sigma\bar{n}/(1-\phi)$ — that is, to the rule-of-thumb growth rate from Proposition 1. For our choice of parameter values, this feasible steady-state growth rate is 4.0% per year. That is, concerns for safety make it optimal in this environment to slow growth considerably relative to what is possible in the steady state.

The reason for this, of course, is the rising value of life, shown for this example in Figure 4. The value of life begins in period 0 at about 100 times annual consumption; if we think of per capita consumption as $30,000 per year, this corresponds to a value of life of $3 million, very much in the range considered in the literature (Viscusi and Aldy 2003; Ashenfelter and Greenstone 2004; Murphy and Topel 2005). Over time, the value of life relative to consumption rises exponentially at a rate that converges to 0.67%, the same rate at which mortality declines.

Figure 4: The Value of Life: Benchmark Case



Note: Simulation results for the competitive equilibrium using the parameter values from Table 1. The value of life rises faster than consumption.

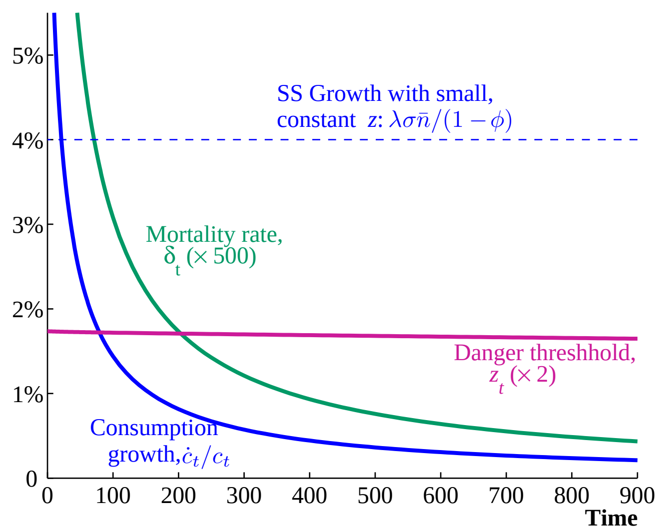
5.2. Numerical Example When $\eta = \infty$

One element of the model that is especially hard to calibrate is the distribution from which technological danger is drawn, $F(z)$. The previous example assumed an exponential distribution so that $\eta = 1$; in particular, the elasticity of the distribution as z approaches zero is finite. However, this need not be the case. Both the Fréchet and the lognormal distributions feature an infinite elasticity. In Proposition 3, we showed that this leads the growth rate of consumption to converge to zero asymptotically. For this example, we consider the Fréchet distribution to illustrate this result: $F(z) = e^{-z^{-\psi}}$ and we set $\psi = 1.1$.[5] Other parameter values are unchanged from the benchmark case shown in Table 1, except we now set $\bar{\delta} = 1$, which is needed to put the value of life in the right ballpark.

Figure 5 shows the dynamics of the economy for this example. The growth rate of consumption now converges to zero as $\eta(z)$ gets larger and larger, mean-

[5] We require $\psi > 1$ so that the mean (and hence conditional expectation) exist. The elasticity of this cdf is $\eta(z) = \psi z^{-\psi}$, so a small value of ψ leads the elasticity to rise to infinity relatively slowly.

Figure 5: Equilibrium Dynamics: Fréchet Case



Note: Dynamics when $F(z)$ is Fréchet, so $\eta = \infty$: growth slows to zero asymptotically. See notes to Figure 3.

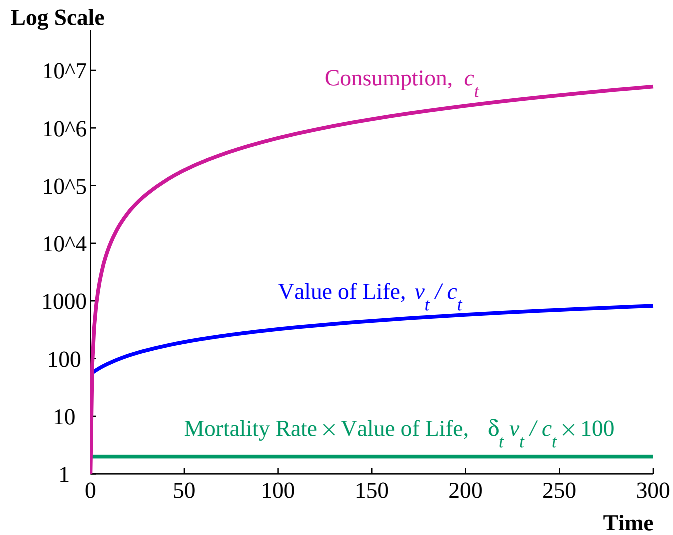
ing that a given decline in the danger threshold eliminates more and more potential ideas. Interestingly, this rising elasticity means that the danger threshold itself declines much more gradually in this example.

Figure 6 — with its logarithmic scale — suggests that this declining consumption growth rate occurs as consumption gets arbitrarily high. The value of life still rises faster than consumption, but the increase is no longer exponential.

6. Discussion and Evidence

The key mechanism at work in this paper is that the marginal utility of consumption falls quickly, leading the value of life to rise faster than consumption. This tilts the allocation in the economy away from consumption growth and toward preserving lives. Exactly this same mechanism is at work in Hall and Jones (2007), which studies health spending. In that paper, $\gamma > 1$ leads to an income effect: as the economy gets richer over time (exogenously), it is optimal to spend

Figure 6: Consumption and the Value of Life: Fréchet Case



Note: Dynamics when $F(z)$ is Fréchet, so $\eta = \infty$: consumption still rises to infinity. See notes to Figure 4.

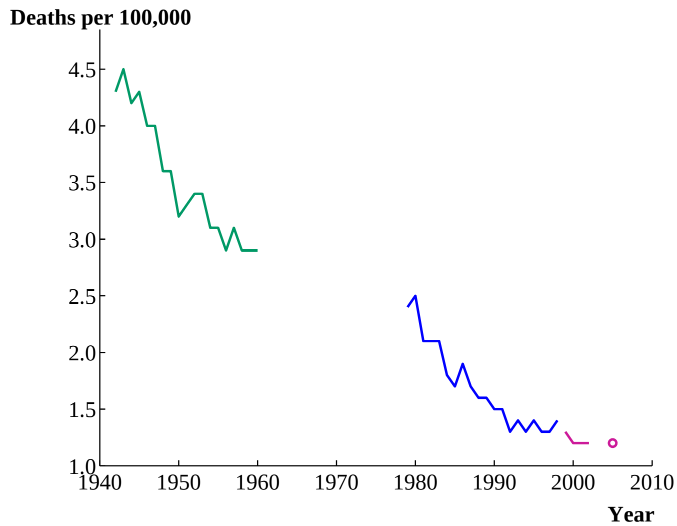
an increasing fraction of income on health care in an effort to reduce mortality. The same force is at work here in a very different context. Economic growth combines with sharply diminishing marginal utility to make the preservation of life a luxury good. The novel finding is that this force has first-order effects on the determination of economic growth itself.

6.1. Empirical Evidence on the Value of Life

Direct evidence on how the value of life has changed over time is surprisingly difficult to come by. Most of the empirical work in this literature is cross-sectional in nature; see Viscusi and Aldy (2003) and Ashenfelter and Greenstone (2004), for example. Two studies that do estimate the value of life over time are Costa and Kahn (2004) and Hammitt, Liu and Liu (2000). These studies find that the value of life rises roughly twice as fast as income, supporting the basic mechanism in this paper.

Less direct evidence may be obtained by considering our changing concerns

Figure 7: Mortality Rate from Accidental Drowning



Note: Taken from various issues of the National Center for Health Statistics, Vital Statistics Data. Breaks in the data imply different sources and possibly differences in methodology.

regarding safety. It is a common observation that parents today are much more careful about the safety of their children than parents a generation ago. Perhaps that is because the world is a more dangerous place, but perhaps it is in part our sensitivity to that danger which has changed.

I am searching for formal data on how safety standards have changed over time and how they compare across countries. One source of information comes from looking at accidental deaths from drowning. Perhaps to a greater extent than for other sources of mortality, it does not seem implausible that advances in health technologies may have had a small effect on drowning mortality: if one is underwater for more than several minutes, there is not much that can be done. Nevertheless, there have been large reductions in the mortality rate from accidental drowning in the United States, as shown in Figure 7. At least in part, these are arguably due to safety improvements.

Safety standards also appear to differ significantly across countries, in a way that is naturally explained by the model. While more formal data is clearly desirable, different standards of safety in China and the United States have been vividly highlighted by recent events in the news. Eighty-one deaths in the United States have been linked to the contamination of the drug heparin in Chinese factories (Mundy 2008). In the summer of 2007, 1.5 million toys manufactured for Mattel by a Chinese supplier were recalled because they were believed to contain lead paint (Spencer and Ye 2008). And in an article on the tragic health consequences for workers producing toxic cadmium batteries in China, the *Wall Street Journal* reports

> As the U.S. and other Western nations tightened their regulation of cadmium, production of nickel-cadmium batteries moved to less-developed countries, most of it eventually winding up in China. "Everything was transferred to China because no one wanted to deal with the waste from cadmium," says Josef Daniel-Ivad, vice president for research and development at Pure Energy Visions, an Ontario battery company. (Casey and Zamiska 2007)

6.2. The Environmental Kuznets Curve

Another interesting application of the ideas in this paper is to the environmental Kuznets curve. As documented by Selden and Song (1994) and Grossman and Krueger (1995), pollution exhibits a hump-shaped relationship with income: it initially gets worse as the economy develops but then gets better. To the extent that one of the significant costs of pollution is higher mortality — as the Chinese cadmium factory reminds us — the declines in pollution at the upper end of the environmental Kuznets curve are consistent with the mechanism in this paper. As the economy gets richer, the value of life rises substantially and the economy features an increased demand for safety.

In fact, the consequences for economic growth are also potentially consistent with the environmental Kuznets curve. One of the ways in which pollution has been mitigated in the United States is through the development of new, cleaner technologies. Examples include scrubbers that remove harmful particulates from industrial exhaust and catalytic converters that reduce automobile emissions. Researchers can spend their time making existing technologies safer or inventing new technologies. Rising concerns for safety lead them to divert effort away from new inventions, which reduces the output of new varieties and slows growth.

7. Conclusion

Safety is a luxury good. For a large class of standard preferences used in applied economics, the value of life rises faster than consumption. The marginal utility associated with more consumption on a given day runs into sharp diminishing returns, and adding additional days of life on which to consume is a natural, welfare-enhancing response. Economic growth therefore leads to a disproportionate concern for safety.

This force is so strong, in fact, that concerns for safety eventually outweigh a society's demand for economic growth. In the economy studied here, safety considerations lead to a conservative bias in technological change that slows growth considerably relative to what could otherwise be achieved. Depending on exactly how the model is specified, this can take the form of an overall reduction in exponential growth to a lower but still positive rate. Alternatively, the exponential growth rate itself may be slowed to zero.

From the standpoint of the growth literature, this is a somewhat surprising result. Some literatures focus on the importance of finding policies to increase the long-run growth rate; others emphasize the invariance of long-run growth to policies. Hence, the result that concerns for safety lead to a substantial reduction in the optimal growth rate is noteworthy.

The finding can also be viewed from another direction, however. A literature on sustainability questions the wisdom of economic growth; for example, see Ehrlich (1968), Meadows et al. (1972), and Mishan (1993). The model studied here permits very strong concerns for safety and human life. And while the consequences are slower rates of economic growth — even rates that slow to zero asymptotically — it is worth noting that the key driving force in the model is an income effect that operates only as consumption goes to infinity. That is, even the most aggressive slowing of growth found in this paper features unbounded growth in individual consumption; it is never the case that all growth should cease entirely.

This paper suggests a number of different directions for future research on the economics of safety. It would clearly be desirable to have precise estimates of the value of life and how this has changed over time; in particular, does it indeed rise faster than income and consumption? More empirical work on how safety standards have changed over time — and estimates of their impacts on economic growth — would also be valuable. Finally, the basic mechanism at work in this paper over time also applies across countries. Countries at different levels of income may have very different values of life and therefore different safety standards. This may have interesting implications for international trade, standards for pollution and global warming, and international relations more generally.

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