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The rational paradigm that dominates modern economics assumes that consumers and other agents independently choose what goods to purchase, maximizing a utility function subject to a budget constraint with prices that, from the household's perspective, are exogenous. Back in the days when this formulation was still controversial, Friedman (1953) argued quite persuasively that economists could justify the assumption of rationality based on biological first principles. Rational decision-makers are optimizers, and natural selection is also an optimization mechanism. Thus it is reasonable to suppose that economic agents will evolve to behave rationally regardless of whether they are conscious of how they maximize their utility, or profit in the case of a firm. While experimentalists have found numerous laboratory examples of subjects behaving irrationally, the rational paradigm continues to predominate because most economists assume that the majority of consumers behave close to rationally and, in the long run, their behavior will converge to rationality.

My own research, however, has uncovered a flaw in this logic. Economists posit that consumers solve a different optimization problem than what biologists posit is solved by natural selection. The distinction is in how the two problems treat the budget constraint. Natural selection maximizes fertility subject to all relevant constraints, including those that involve interactions with other members of the species and other species. In *The Origin of Species*, Darwin preempted many creationist arguments by pointing out how natural selection can affect traits not strictly related to procreation through its action on what economists would term externalities. For example, among bees only a small fraction of the population is equipped to reproduce, yet the behavior of the sterile worker bees is still highly evolved.

This observation pertains to the consumer's problem because the prices of their purchases are not really exogenous. The prices depend on the aggregate of the choices of all individuals. If natural selection is in fact optimizing utility, it would account for this pecuniary externality. Factor prices would depend on consumers' choices in the budget constraint.

In an infinite-horizon, representative-agent model, the Welfare Theorems imply that the solution to the standard consumer's problem is the optimal allocation, so it is innocuous to assume consumers view prices as exogenous. Indeed, the equivalence of the solutions for the standard consumer's problem and a Pareto social planner's problem is undoubtedly the reason why economists are so wedded to the standard definition of rationality.

But real people do not live forever. In an overlapping-generations (OLG) model, whether the optimization is done with exogenous prices or with the equilibrium conditions as constraints makes a difference. Frank Caliendo, Emin Gahramanov, and I established in "Optimal Irrational Behavior" (published in *Journal of Economic Behavior and Organization*) that, with technology and preferences calibrated so the rational competitive equilibrium is dynamically efficient, there will almost surely be irrational behaviors that yield higher utility in general equilibrium. A biologist would maintain that an OLG economy should ultimately evolve to the optimal irrational equilibrium instead of the rational equilibrium.

This is not to imply that we have evolved to an optimal irrational equilibrium. My paper "Can High Discount Rates Increase Capital Accumulation?" (a working paper co-written with Emin Gahramanov and Xueli Tang) shows there is no preference model that generates optimal irrational behavior consistent with the observed capital-output ratio of the United States. Even with very high discount rates, optimally irrational behavior would involve a counterfactually

large amount of saving. Indeed, the optimal irrational capital-output ratio can, counterintuitively, increase with the discount rate.

Nevertheless, we do observe behaviors that are extremely difficult to explain in the rational paradigm yet are quite sensible if our choices have adapted to pecuniary externalities. Perhaps the best example was discovered serendipitously when Emin Gahramanov and I extended the optimal irrational behavior concept to allow for mortality risk. We had theorized that mortality risk might curb some of the excessive saving behavior, which initially appeared to be a consequence of delaying consumption to the very end of the life span. That hypothesis proved wrong. In some cases mortality risk enhances the spike in consumption at the end of life. This spike turns out to have negligible impact on welfare. It is, instead, the optimal compromise between the welfare advantages of saving more and the assumption that households should die broke. The spike can be made economically irrelevant by allowing for an epsilon probability of surviving to a Methuselahian age of 1000.

More interesting results obtain when we introduce annuities to the model with mortality risk (“Is It Really Good to Annuitize?” co-authored with Emin Gahramanov and Xueli Tang and published in *Journal of Economic Behavior and Organization*). One of the most robust theorems in lifecycle economics is Yaari’s (1965) proposition that rational households will finance their own consumption stream by investing in longevity annuities. A longevity annuity pools the funds of a cohort of investors, paying a stream of income to an annuity holder until the holder dies, at which point his remaining funds are allocated to the surviving investors. This last part means the expected return of longevity annuities is higher than for other investments. A rational investor who only cares about his own consumption will invest exclusively in longevity annuities, and a rational investor with a bequest motive will still invest a significant fraction of his wealth in longevity annuities. Empirically, though, hardly anybody invests in annuities.

It was very surprising then when we found that welfare was higher in general equilibrium if we shut down annuities markets. This is true generically for the optimal irrational equilibrium, but it is also true of the rational equilibrium for most preference calibrations (Heijdra et al (2014) also made the latter discovery independently of us).

Accidental bequests explain this unexpected welfare reversal. Even if households draw no direct utility from passing an estate to their heirs, they still benefit when they inherit a bequest from their precursors. If everyone invests via longevity annuities, there can be no accidental bequests.

My job-market paper, “Optimal Decumulation of Wealth in General Equilibrium,” made a finer accounting of the pros and cons of longevity annuities and also considers bond annuities that pay a constant stream of income for a fixed length of time. Ownership of the assets financing a bond annuity remains with the household’s estate in the event of the household’s death, so bond annuities will still yield an accidental bequest where longevity annuities do not. Since bond annuities are redundant assets, they have not received much attention in the annuities literature. Yaari’s result applies strictly to longevity annuities, which pay a higher expected return. However, in general equilibrium, welfare gains are typically even higher if households are forced to invest their retirement wealth in bond annuities than the gains obtained if households are prevented from annuitizing. This is because bond annuities conserve wealth longer than alternative investment strategies. For a household to have a constant consumption stream till death, it has to maintain a large saving till the end of life. This saving leads to a higher accidental bequest when the household eventually dies and also contributes to a larger capital stock, both of which increase lifetime utility.

The fact that bond annuities can increase utility in equilibrium is significant because it may resolve another puzzle in the lifecycle consumption literature. Although most households do not invest in annuities, they also do not spend down their assets like they rationally should in the absence of annuity markets (Davies (1981)). Instead, they conserve their wealth and maintain a smooth consumption path. In other words, they consume as though they have invested in bond annuities. Since bond annuities are redundant assets, there are many ways to achieve the same allocation without employing bond annuities, and if the majority of households do this they will enjoy higher utility.

Thus households have informally coordinated on an equilibrium with higher welfare than the rational competitive equilibrium. Personally, I believe that biological forces are responsible for this coordination; this is a testable proposition as I will detail below. Regardless of the explanation, if households are haphazardly enjoying the benefits of investing in bond annuities, they are probably doing so inefficiently, which would mean there is a Pareto-improving transition to an even better equilibrium.

This conjecture is reinforced by the work of Conesa and Garriga (2008), who have shown that the common wisdom that there is no Pareto-improving way to reform Social Security is based on the false premise that taxes are nondistortionary, which is an artifact of the simplifying assumption that labor is exogenous. With endogenous labor, almost any beneficial reform that one can imagine can be implemented with a Pareto-improving transition. In a paper tentatively titled “How to Design a Welfare- and Pareto-Improving Social Security System,” I show how tremendous gains could be achieved if the present pay-as-you-go Social Security system is replaced by a savings match like Turkey. The existing US tax code incorporates saving matches on a small scale through tax deferments on individual retirement accounts, 401(k), and similar accounts. In employer-sponsored retirement accounts there may also be an explicit match financed by the employer. But preliminary calculations show it is both optimal and feasible for the government to match all private saving at a rate of close to 100%, financing this subsidy with taxes on labor income.

Many economists are of the view that the government is incapable of improving the private sector of the economy, but this is simply not true in a world where human beings are mortal. In practice public-choice frictions often—perhaps even universally—corrupt the government’s efforts to better our lot, but that does not imply governments are physically incapable of raising the general welfare.

Looking forward, the goal of my research agenda is to establish a biological paradigm of economics that encompasses and expands upon my existing findings. Theoretically, overlapping-generations models are readily modified to take seriously the notion that utility is a function of fertility. This would involve remaking the overlapping-generations model as an agent-based model in which households follow consumption rules that are passed on with mutation to the next generation. When it dies, each household will be replaced by a stochastic number of children in which the distribution of family size is a function of the parent’s lifetime utility. I have not yet developed the software to compute what happens in this agent-based model. However, it is relatively easy to show the pecuniary externality will prevent the model from converging to a steady state in which the mean saving rate equals the rational saving rate. This model cannot converge to a rational competitive equilibrium.

What is especially appealing about this model is that it is immune to the criticism of most economic models that the primitives of consumer behavior are unobservable. In the agent-based model utility is not an abstract concept invented by 19<sup>th</sup>-Century philosophers. If fertility is

utility, this will have strong testable predictions that I intend to study in concert with an econometrician.

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