87. Siegel, Richard W., Evelyn Hu, and M. C. Roco. 1999. *Nanostructure Science and Technology*. Dordrecht, Netherlands: Kluwer.
88. Slater, Philip Elliot. 1970. The Pursuit of Loneliness: American Culture at the Breaking Point. Boston, Beacon Press.
89. Stark, Rodney and William Sims Bainbridge. 1985. *The Future of Religion*. Berkeley: University of California Press.
90. Steckel, Richard H., and Roderick Floud (eds.). 1997. *Health and Welfare During Industrialization*. Chicago: University of Chicago Press.
91. Thomas, Neil, and Neil Price. 1999. "The Role of Deevelopment in Global Fertility Decline," *Futures*, 31: 779-802.
92. Tönnies, Ferdinand. 1887. *Community and Society*. East Lansing, Michigan: Michigan State University Press [1957].
93. Population Division, Department of Economic and Social Affairs, United Nations, *World Population Prospects: The 2000 Revision* (New York: United Nations, 2001).
94. Vogel, Ezra F. 1979. *Japan as Number One: Lessons for America*. Cambridge, Massachusetts: Harvard University Press.
95. Watson, Robert T, Marufu C. Zinyowera, Richard C. Moss, and David J. Dokken (eds.). 2001. *Climate Change 2001*. Geneva, Switzerland: Intergovernmental Panel on Climate Change c/o World Meterological Organization, see www.ipcc.ch and www.grida.no/climate/ipcc/regional/index.htm.
96. Wattenberg, Ben J. 1987. *The Birth Dearth*. New York: Ballantine.
97. Wilson, Edward O. 1998. *Consilience: The Unity of Knowledge*. New York: Random House.

FIVE NANOTECH SOCIAL SCENARIOS

Robin Hanson – George Mason University

During the dotcom boom, popular discussions about the future of the internet often included claims of dramatic social implications; the "new economy" was said to follow new rules (Kelly, 1998). This hype was ridiculed after the dotcom crash, but the internet did in fact bring real changes, with non-trivial social implications. And early on economists were able to play the important role of analyzing these claims, and distinguishing the hype from real changes. For example, in *Information Rules*, Carl Shapiro and Hal Varian did a great job of using economic theory to distinguish plausible from implausible claims about the internet (Shapiro & Varian, 1999).

Popular discussions of nanotechnology have also included many claims of dramatic social implications (Drexler, Peterson, & Pergamit, 1991; Stephenson, 1995). Some even point to a new "economy of abundance" (Bruns, 2000). Naturally, many others consider these claims to be hype. It is my hope that, as with the internet, economic analysis might help to distinguish plausible from implausible claims about nanotechnology.

What assumptions about this technology should we base our economic analysis on? At one extreme, some think of "nanotechnology" as a new name for "material science" and "chemistry." This view suggests that while advances in these fields will continue, there is little to say regarding social implications beyond general analysis of long term growth, and perhaps analyzes of certain new enabled products, such as better surveillance. A variation on this position suggests that we are seeing the coalescence of a new research specialty, a view that may have some minor implications regarding the organization of research. At the other extreme, some think of "nanotechnology" as the technology of a new device, the “assembler,” which like the computer will induce large social changes via its novel and general capabilities (Drexler, 1992). (Others are very skeptical about such scenarios (Baum, 2003).)

Economists should not choose sides in these technical disputes. While radical nanotechnology scenarios might be less likely, if realized they would have larger social implications, and we already understand the conservative scenarios reasonably well. Furthermore, it was most likely the public’s interest in and concern about more radical scenarios that led Congress to request an analysis of the social implications of nanotechnology. Economists should therefore consider the social implications of radical nanotechnology scenarios. Since mild scenarios are a priori more likely than radical scenarios, however, we should also think about how these radical scenarios might be only partially realized.

The short informal analysis in the remainder of this paper is a very preliminary attempt at such an analysis, intended primarily to indicate what might be possible with a more careful analysis. A range of assumptions and future production costs are presented which define five economic scenarios spanning the range from conservative to radical nanotechnology scenarios. We start with the most conservative scenario, and then each scenario adds more assumptions and has additional social implications. The goal here is to identify the economic assumptions behind an imaginable radical nanotechnology scenario, as well as to some milder and more likely variations.

Atomic Precision

> Atom-scale manufacturing is feasible; we put some atoms where we want.

Such abilities may eventually allow many new products, such as cheaper and smaller computers and sensors, and perhaps tiny medical implants. Exactly which products are feasible would depend on exactly which assembly contexts allow such precision, and at what cost. Economic growth could go far before hitting limits. Particular products may have particular implications.

General Plants

> General purpose manufacturing plants, using fewer kinds of inputs, displace most special purpose plants, as general purpose computers have displaced most special purpose signal processors. (This is mature “3D printing” or “direct manufacturing” (Imato, 2003))

Computers displaced special purpose signal processors because of scale economies in computer production (the more we made the cheaper they get) and because it was usually easier to program a general computer for a particular task than to design and build a special purpose device for that task. These advantages usually outweighed the fact that special purpose devices could produce the same results faster, with fewer transistors, and with less energy.

Similarly, for more general plants to dominate, the scale economies of making them, and the reduced cost of designing a production plan and retooling for it, would have to overcome the efficiency advantages (e.g., time, energy, inputs) of specialized plants. Generality is relative of course; a “general” plant might make most consumer goods, most kinds of household furniture, or just most kinds of mattresses. More general plants should use fewer kinds of inputs, have production costs that depend on fewer design details, and cost more themselves to design. The skills of manufacturing workers would be less specialized to particular kinds of products.

The reduced design and retooling costs of more general plants should allow more product differentiation, and more rapid product evolution. When transport costs matter, production should be at the general plants of the relevant type nearest to each customer.

Local Production

> Small general plants, located in or near homes, dominate manufacturing.

This requires a high level of plant generality, and requires that production processes, including diagnosis and repair of problems, be almost fully automated, with human intervention rare. Such high levels of generality and automation are harder to design. But once such devices existed, they would allow hobbyist designers of products (and production plans), as PCs allowed hobbyist programmers. As with PCs today, open source product design and sharing of stolen product designs could become issues. Any companies who owned the standards for such devices, such as Intel and Microsoft do today for PCs, would hold a commanding position in the economy.

In this scenario the costs of transportation of products and of labor for their production have been mostly eliminated. What remain are marginal costs of energy, inputs, waste disposal, plant rental, marketing (people learning about product price, quality, and features), and regulation (such as of use externalities), and fixed costs of design, plant setup, marketing, and regulation.

Software and cable TV companies now offer a few large packages of diverse products, in order to better price-discriminate. (This works when marginal costs are low and item values are not too positively correlated (Bakos & Brynjolfsson, 1999).) Future consumers might similarly be offered a few lifestyle packages costing most of their income and entitling them to use a wide range of product designs (e.g., clothes, furniture, food, cars) at their local plant (if the customer pays for inputs, energy, etc.). This would require a lot of coordination by (or concentration of) sellers of consumer good designs, and deterrence of sharing between buyers of different packages. Geographic separation, which now lets cruise ships and resorts offer all you can eat and play deals, might help deter sharing.

Over-Capacity

> Local general plants so fast and cheap that they are usually idle, like PCs now.

Most home PCs today are usually idle (or doing very low value work); they are as capable as they are because they are cheap, and on occasion we want that much capacity. Similarly, if it is cheap enough to create local general plants, they might usually be basically idle, and be only rarely used at capacity. If so, the relevant cost of capital would usually be very low; the marginal costs of most products would be inputs, energy, waste disposal, marketing, and regulation. Fixed costs of design, regulation, and marketing would usually dominate total costs, as with software and music today. In this scenario, “information economics” would describe most consumer goods (Shapiro & Varian, 1999).

Self-Reproduction

> A local manufacturing plant can create a copy of itself in much less than a year.

Once we add in this assumption, we reach the most radical nanotech scenarios (Drexler et al., 1991; Stephenson, 1995), where plants built to atomic-precision can reproduce themselves (as all life forms do today), and in addition be programmed to produce other products (as a few life forms can now do in some limited ways). The problem of designing such entities seems very hard, but solving this design problem is one possible route to achieving over-capacity of local general plants, and perhaps soon.

Self-reproduction could give a large and sudden, and hence destabilizing, cost advantage to the commercial or military power that first achieves this ability. How large an advantage depends on just-prior costs, and how sudden an advantage depends on self-reproduction time, the development lead held by the first successful group, and the availability of product designs taking advantage of this reduced cost. Self-reproducing military or terrorist weapons might be a concern, if these entities were small enough and reproduced fast enough.

Conclusion

The five social scenarios presented above, with their matching economic assumptions and social implications, span the range between conservative and radical nanotechnology. While the conservative scenarios are more likely, the radical scenarios have larger social implications, and so are worth considering. The preliminary analysis here of these scenarios is intended primarily to indicate what might be possible with a more careful analysis.

References

98. Bakos, Y., & Brynjolfsson, E. (1999). Bundling Information Goods: Pricing, Profits, and Efficiency. *Management Science*, *45* (12), 1613–1630.
99. Baum, R. (2003). Nanotechnology: Drexler and Smalley make the case for and against ’molecular assemblers’. *Chemical and Engineering News*, *81* (48), 37–42.
100. Bruns, B. (2000). Nanotechnology and the Commons: Implications of Open Source Abundance in Millennial Quasi-Commons. Tech. rep.. http://www.indiana.edu/ workshop/ papers/bruns110100.pdf.
101. Drexler, E., Peterson, C., & Pergamit, G. (1991). *Unbounding the Future: The Nanotechnology Revolution*. William Morrow and Company, New York.
102. Drexler, K. E. (1992). *NanoSystems*. John Wiley and Sons, New York.
103. Imato, I. (2003). Instant Manufacturing. *Technology Review*.
104. Kelly, K. (1998). New Rules for the New Economy: 10 Radical Strategies for a Connected World. Viking Press, New York.
105. Shapiro, C., & Varian, H. R. (1999). *Information Rules: A Strategic Guide to the Network Economy*. Harvard Business School Press, Boston.
106. Stephenson, N. (1995). *Diamond Age: Or a Young Lady’s Illustrated Primer*. Bantam Books, New York.

*For their comments, I thank Curt Adams, Damien Broderick, Dan Clemmensen, Alejandro Dubrovsky, Hal Finney, Eugen Leitl, Max More, Chris Peterson, Chris Phoenix, and Alex Tabarrok. For financial support, I thank the Center for Study of Public Choice, the Mercatus Center, and the International Foundation for Research in Experimental Economics.

TECHNOLOGICAL REVOLUTIONS AND THE LIMITS OF ETHICS IN AN AGE OF COMMERCIALIZATION

John Trumpbour – Harvard Law

Nanotechnology has raised vital questions about the social impacts of new technologies. This essay will try to supply some historical perspectives on technological revolutions by assessing 1)