Economic Growth

by Paul M. Romer

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Compound Rates of Growth

In the modern version of an old legend, an investment banker asks to be paid by placing one penny on the first square of a chess board, two pennies on the second square, four on the third, etc. If the banker had asked that only the white squares be used, the initial penny would have doubled in value thirty-one times, leaving $21.5 million on the last square. Using both the black and the white squares would have made the penny grow to $92,000,000 billion.

People are reasonably good at forming estimates based on addition, but for operations such as compounding that depend on repeated multiplication, we systematically underestimate how quickly things grow. As a result, we often lose sight of how important the average rate of growth is for an economy. For an investment banker, the choice between a payment that doubles with every square on the chess board and one that doubles with every other square is more important than any other part of the contract. Who cares whether the payment is in pennies, pounds, or pesos? For a nation, the choices that determine whether income doubles with every generation, or instead with every other generation, dwarf all other economic policy concerns.

Growth in Income Per Capita

You can figure out how long it takes for something to double by dividing the growth rate into the number 72. In the 25 years between 1950 and 1975, income per capita in India grew at the rate of 1.8% per year. At this rate, income doubles every 40 years because 72 divided by 1.8 equals 40. In the 25 years between 1975 and 2000, income per capita in China grew at almost 6% per year. At this rate, income doubles every 12 years.

These differences in doubling times have huge effects for a nation, just as they do for our banker. In the same 40-year timespan that it would take the Indian economy to double at its slower growth rate, income would double three times, to eight times its initial level, at China's faster growth rate.

From 1950 to 2000, growth in income per capita in the United States lay between these two extremes, averaging 2.3% per year. From 1950 to 1975, India, which started at a level of income per capita that was less than 7% of that in the United States, was falling even farther behind. Between 1975 and 2000, China, which started at an even lower level, was catching up.

China grew so quickly partly because it started from so far behind. Rapid growth could be achieved in large part by letting firms bring in ideas about how to create value that were already in use in the rest of the world. The interesting question is why India couldn't manage the same trick, at least between 1950 and 1975.

Growth and Recipes

Economic growth occurs whenever people take resources and rearrange them in ways that are more valuable. A useful metaphor for production in an economy comes from the kitchen. To create valuable final products, we mix inexpensive ingredients together according to a recipe. The cooking one can do is limited by the supply of ingredients, and most cooking in the economy produces undesirable side effects. If economic growth could be achieved only by doing more and more of the same kind of cooking, we would eventually run out of raw materials and suffer from unacceptable levels of pollution and nuisance. Human history teaches us, however, that economic growth springs from better recipes, not just from more cooking. New recipes generally produce fewer unpleasant side effects and generate more economic value per unit of raw material.

Take one small example. In most coffee shops, you can now use the same size lid for small, medium, and large cups of coffee. That wasn't true as recently as 1995. That small change in the geometry of the cups means that a coffee shop can serve customers at lower cost. Store owners need to manage the inventory for only one type of lid. Employees can replenish supplies more quickly throughout the day. Customers can get their coffee just a bit faster. Such big discoveries as the transistor, antibiotics, and the electric motor attract most of the attention, but it takes millions of little discoveries like the new design for the cup and lid to double average income in a nation.

Every generation has perceived the limits to growth that finite resources and undesirable side effects would pose if no new recipes or ideas were discovered. And every generation has underestimated the potential for finding new recipes and ideas. We consistently fail to grasp how many ideas remain to be discovered. The difficulty is the same one we have with compounding: possibilities do not merely add up; they multiply.

In a branch of physical chemistry known as exploratory synthesis, chemists try mixing selected elements together at different temperatures and pressures to see what comes out. About a decade ago, one of the hundreds of compounds discovered this way—a mixture of copper, yttrium, barium, and oxygen—was found to be a superconductor at temperatures far higher than anyone had previously thought possible. This discovery may ultimately have far-reaching implications for the storage and transmission of electrical energy.

To get some sense of how much scope there is for more such discoveries, we can calculate as follows. The periodic table contains about a hundred different types of atoms, which means that the number of combinations made up of four different elements is about $100 \times 99 \times 98 \times 97 = 94,000,000$. A list of numbers like 6, 2, 1, 7 can represent the proportions for using the four elements in a recipe. To keep things simple, assume that the numbers in the list must lie between 1 and 10, that no fractions are allowed, and that the smallest number must always be 1. Then there are about 3,500 different sets of proportions for each choice of four elements, and $3,500 \times 94,000,000$ (or 330 billion) different recipes in total. If laboratories around the world evaluated 1,000 recipes each day, it would take nearly a million years to go through them all. (If you like these combinatorial calculations, try to figure out how many different coffee drinks it is possible to order at your local shop. Instead of moving around stacks of cup lids, baristas now spend their time tailoring drinks to each individual palate.)

In fact, the previous calculation vastly underestimates the amount of exploration that remains to be done because mixtures can be made of more than four elements, fractional proportions can be selected, and a wide variety of pressures and temperatures can be used during mixing.

Even after correcting for these additional factors, this kind of calculation only begins to suggest the range of possibilities. Instead of just mixing elements together in a disorganized fashion, we can use chemical reactions to combine elements such as hydrogen and carbon into ordered structures like polymers or proteins. To see how far this kind of process can take us, imagine the ideal chemical refinery. It would convert abundant, renewable resources into a product that humans value. It would be smaller than a car, mobile so that it could search out its own inputs, capable of maintaining the temperature necessary for its reactions within narrow bounds, and able to automatically heal most system failures. It would build replicas of itself for use after it wears out, and it would do all of this with little human supervision. All we would have to do is get it to stay still periodically so that we could hook up some pipes and drain off the final product.

This refinery already exists. It is the milk cow. And if nature can produce this structured collection of hydrogen, carbon, and miscellaneous other atoms by meandering along one particular evolutionary path of trial and error (albeit one that took hundreds of millions of years), there must be an unimaginably large number of valuable structures and recipes for combining atoms that we have yet to discover.

Objects and Ideas

Thinking about ideas and recipes changes how one thinks about economic policy (and cows). A traditional explanation for the persistent poverty of many less developed countries is that they lack objects such as natural resources or capital goods. But Taiwan stared with little of either and still grew rapidly. Something else must be involved. Increasingly, emphasis is shifting to the notion that it is ideas, not objects, that poor countries lack. The knowledge needed to provide citizens of the poorest countries with a vastly improved standard of living already exists in the advanced countries. If a poor nation invests in education and does not destroy the incentives for its citizens to acquire ideas from the rest of the world, it can rapidly take advantage of the publicly available part of the worldwide stock of knowledge. If, in addition, it offers incentives for privately held ideas to be put to use within its borders—for example, by protecting foreign patents, copyrights, and licenses, by permitting direct investment by foreign firms, by protecting property rights, and by avoiding heavy regulation and high marginal tax rates—its citizens can soon work in state-of-the-art productive activities.

Some ideas such as insights about public health are rapidly adopted by less developed countries. As a result, life expectancy in poor countries is catching up with the leaders faster than income per capita. Yet governments in poor countries continue to impede the flow of many other kinds of ideas, especially those with commercial value. Automobile producers in North America clearly recognize that they can learn from ideas developed in the rest of the world. But for decades, car firms in

India operated in a government-created protective time warp. The Hillman and Austin cars produced in England in the 1950s continued to roll off production lines in India through the 1980s. After independence, India's commitment to closing itself off and striving for self-sufficiency was as strong as Taiwan's commitment to acquiring foreign ideas and participating fully in world markets. The outcomes—grinding poverty in India and opulence in Taiwan—could hardly be more disparate.

For a poor country like India, enormous increases in standards of living can be achieved merely by letting in the ideas held by companies from industrialized nations. With a series of economic reforms that started in the early 1990s, India has begun to open itself up to these opportunities. For some of its citizens such as the software developers who now work for firms located in the rest of the world, these improvements in standards of living have become a reality. This same type of opening up is causing a spectacular transformation of life in China. Its growth in the last 25 years of the twentieth century was driven to a very large extent by foreign investment by multinational firms.

Leading countries like the United States, Canada, and the members of the European Union cannot stay ahead merely by adopting ideas developed elsewhere. They must offer strong incentives for discovering new ideas at home, and this is not easy to do. The same characteristic that makes an idea so valuable—everybody can use it at the same time—also means that it is hard to earn an appropriate rate of return on investments in ideas. The many people who benefit from a new idea can too easily free-ride on the efforts of others.

After the transistor was invented at Bell Labs, many applied ideas had to be developed before this basic science discovery yielded any commercial value. By now, private firms have developed improved recipes that have brought the cost of a transistor down to less than a millionth of its former level. Yet most of the benefits from those discoveries have been reaped not by the innovating firms, but by the users of the transistors. In 1985, I paid a thousand dollars per million transistors for memory in my computer. In 2005, I paid less than ten dollars per million, and yet I did nothing to deserve or help pay for this windfall. If the government confiscated most of the oil from major discoveries and gave it to consumers, oil companies would do much less exploration. Some oil would still be found serendipitously, but many promising opportunities for exploration would be bypassed. Both oil companies and consumers would be worse off. The leakage of benefits such as those from improvements in the transistor acts just like this kind of confiscatory tax and has the same effect on incentives for exploration. For this reason, most economists support government funding for basic scientific research. They also recognize, however, that basic research grants by themselves will not provide the incentives to discover the many small applied ideas needed to transform basic ideas such as the transistor or web search into valuable products and services.

It takes more than scientists in universities to generate progress and growth. Such seemingly mundane forms of discovery as product and process engineering or the development of new business models can have huge benefits for society as a whole. There are, to be sure, some benefits for the firms that make these discoveries, but not enough to generate innovation at the ideal rate. Giving firms tighter patents and copyrights over new ideas would increase the incentives to make a new discovery, but might also make it much more expensive to build on previous discoveries.

Tighter intellectual property rights could therefore be counter-productive and slow growth down.

The one safe measure that governments have used to great advantage has been to use subsidies for education to increase the supply of talented young scientists and engineers. They are the basic input into the discovery process, the fuel that fires the innovation engine. No one can know where newly trained young people will end up working, but nations that are willing to educate more of them and let them follow their instincts can be confident that they will accomplish amazing things.

Meta-Ideas

Perhaps the most important ideas of all are meta-ideas. These are ideas about how to support the production and transmission of other ideas. The British invented patents and copyrights in the seventeenth century. North Americans invented the modern research university and the agricultural extension service in the nineteenth century, and peer-reviewed competitive grants for basic research in the twentieth century. The challenge now facing all of the industrialized countries is to invent new institutions that encourage a higher level of applied, commercially relevant research and development in the private sector.

As national markets for talent and education merge into unified global markets, opportunities for important policy innovation will surely emerge. In basic research, the United States is still the undisputed leader, but in key areas of education, other countries are surging ahead. Many of them have already discovered how to train a larger fraction of their young people as scientists and engineers.

We do not know what the next major idea about how to support ideas will be. Nor do we know where it will emerge. There are, however, two safe predictions. First, the country that takes the lead in the twenty-first century will be the one that implements an innovation that more effectively supports the production of new ideas in the private sector. Second, new meta-ideas of this kind will be found.

Only a failure of imagination—the same one that leads the man on the street to suppose that everything has already been invented—leads us to believe that all of the relevant institutions have been designed and that all of the policy levers have been found. For social scientists, every bit as much as for physical scientists, there are vast regions to explore and wonderful surprises to discover.

About the Author

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Further Reading

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