KNOWLEDGE AND THE WEALTH OF NATIONS

A Story of Economic Discovery

DAVID WARSH

"A fascinating journey through the world of economic thought—and the lives of economists—from Adam Smith to the present day."
—Paul Krugman, *New York Times Book Review*

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To the memory of

E. LAWRENCE (LAURY) MINARD III,
1950–2001

The construction of a model, or of any theory for that matter (or the writing of a novel, a short story or a play) consists of snatching from the enormous and complex mass of facts called reality a few simple, easily-managed key points which, when put together in some cunning way, become for certain purposes a substitute for reality itself.

—EVSEY DOMAR, *Essays in the Theory of Economic Grow*

Truth emerges more readily from error than from confusion.

—FRANCIS BACON, *Novum Organu*

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PREFACE

This book tells the story of a single technical paper in economics—the events leading up to its publication in 1990 and some subsequent changes in our understanding of the world. My subsidiary aim is to convey something about how economics is done today in universities, for it is there, not in central banks or government offices or Wall Street firms, that the most important work takes place.

Between 1979 and 1994 a remarkable exchange unfolded among economists in hard-to-read technical journals concerning economic growth: what it is, what makes it happen, how we share it, how we measure it, what it costs us, and why it is worth having. Such was the sense of novelty that emerged from this exchange—of learning how to understand something for the first time, to write it down in such a way as to perpetuate the understanding of it, of *discovery*, in other words—that this literature quickly became known as "new growth theory." Many persons made contributions. A new generation rose to prominence in the field. Yet the issues themselves and the manner of their resolution remain unfamiliar to a wider audience.

I am an economic journalist, for many years a newspaperman, not an economist or a historian o economic thought. My mathematics is rudimentary, but my English is good, my skepticism fluent, a my background knowledge of economics fairly extensive from having followed the field for many years. The book is written from an outsider's point of view—an appreciative outsider, but one who hasn't altogether surrendered his skepticism. In other words, I am a civilian and a believer in civilian control.

Why focus on a single skein of work? Progress in economics these last thirty years has been rapid. Its scope has broadened and its generality increased. There are a great many stories to report. The new growth story first caught my eye because I was interested in specialization and the growth o knowledge. I've come to see it since, however, as a *representative* story—an illustration of how mathematics became the working language of modern economics, of why its practitioners deem thei formal methods to have been such a success.

The new growth story shows how economic discovery occurs—in intense intellectual competition among small groups of researchers working in rival universities. From this competition emerge occasional transformations in understandings of the world, reflecting simultaneously the cumulative work of generations *and* the border-crossing journeys of research partners or, perhaps, a single person. Gradually these transformations make their way outward, like ripples spreading from a pebble thrown on a pond, until what originally was *their* understanding becomes *our* understanding a well.

Even today a majority of economists may not have made up their minds about what happened to their subject during the 1980s and early 1990s, in the subdiscipline of their field that is concerned wi growth and development. Specialists tend to keep their heads down, after all. Nor have all the parties to the argument capitulated. Some readers may prefer to skip the backstory in this book and go directly to the various guides and textbooks that are beginning to appear.* They will be missing altogether a good story (and an important lesson) in their haste.

Many of the more public events in this story I covered as they occurred, often in meetings in stuffy hotel rooms on sunny days and in the conversation afterwards—a strange kind of news indeed. It is humbling to look back and see how slowly the significance of these developments dawned on me and how much longer it took me to put it into words on paper. But then, if it had been obvious, it

and how much longer it took me to put it into words on paper. But then, if it had been obvious, it wouldn't be news.

I talked to many people along the way. Almost all of them talked back, with varying degrees of candor. My thanks to all. Economists are a good lot, and they like a yarn as well as the next person. Only toward the end did I realize how much they were interested in keeping secret. Economists have their foibles too.

INTRODUCTION

One of the oldest chestnuts in the inventory of our common sense is this: Give a man a fish, and you feed him for a day. Teach a man how to fish, and you feed him for a lifetime. To which it now must be added, invent a better method of fishing, or of farming fish, selling fish, changing fish (through genetic engineering), or preventing overfishing in the sea, and you feed a great many people, because these methods can be copied virtually without cost and spread around the world. Of course, depending on the circumstances, your invention can make *you* rich as well. New ideas, more than savings or investment or even education, are the keys to prosperity, both to private fortunes, large and small, and to the wealth of nations—to economic growth, in other words, with its incalculable benefits for all. In the background are the intricate rules of the game that we summarize as the rule of law—and politics.

Yet it was not until October 1990 when a thirty-six-year-old University of Chicago economist named Paul Romer published a mathematical model of economic growth in a mainstream journal that the economics of knowledge at last came into focus, after more than two centuries of informal and uneasy presence in the background. The title of the paper was at once deceptively simple and intimidating: "Endogenous Technological Change."

The thirty-two-page article in the *Journal of Political Economy* observed all the ordinary conventions of scientific writing: passive voice, mathematical analysis, modest claims. There were careful citations of earlier work in the same tradition, especially the paper which it sought to supplant and on which it sought to build, "A Contribution to the Theory of Economic Growth," published in 1956 by Robert Solow.

The first paragraph contained a sentence that was initially more puzzling than not: "The distinguishing feature of…technology as an input is that it is neither a conventional good nor a public good; it is a nonrival, partially excludable good…."

And thereupon hangs a tale. For that particular sentence, written more than fifteen years ago and still not widely understood, initiated a far-reaching conceptual rearrangement in economics. It did so by augmenting the familiar distinction between "public" goods, supplied by governments, and "private" goods, supplied by market participants, with a second opposition, between "rival" and "nonrival" goods—between goods whose corporeality makes possible their absolute possession and limited sharing (an ice-cream cone, a house, a job, a Treasury bond) and goods whose essence can be written down and stored in a computer as a string of bits and shared equally by many persons at the same time practically without limit (a holy book, a language, the calculus, the principles of design of a bicycle). Inevitably, most goods must consist of at least a little of each. In between these extremes lie myriad interesting possibilities.

A designer dress. The operating system software in a personal computer. A jazz concert. A Beatles recording. The design of a new computer chip. The coded signal from a communications satellite. A map of the human genome. The molecular structure of a new drug—and the secrets of its efficient manufacture. A genetically altered seed—and the series of manipulations that produced it. A Picasso painting, both the canvas itself with its brushstrokes and layers of paint, and its myriad reproductions. A "Baby on Board" sign in an auto window. The text of the book you are reading now.

The equation in Chapter Two. All these are nonrival goods because they can be copied or shared and used by many people at the same time. Most are partially *excludable* as well, meaning that access to them can in some degree be controlled, at least in principle. Rival goods are *objects* and nonrival

them can in some degree be controlled, at least in principle. Rival goods are *objects* and nonrival goods are *ideas*—"atoms" and "bits," in a catchy phrase borrowed from computing, where ideas are expressed in strings of binary bits; or "convexities" and "nonconvexities," in the more austere language of mathematics.

By itself the concept of nonrivalry wasn't altogether new to economics. For more than a century public finance specialists had used a series of often confusing terms to explain the source of "market failure"—to describe the underlying commonality of, say, national defense or streetlights, a new bridge or the warning provided by a lighthouse. Nonrivalry took its place among them in the 1960s. I was by marrying nonrivalry to the concept of excludability, and applying the distinction where it had not been employed before, that Romer cast a new light on the ubiquitous role of ideas in the economics of everyday life—meaning trade secrets, formulas, trademarks, algorithms, mechanisms, patents, scientific laws, designs, maps, recipes, procedures, business methods, copyrights, bootleg copies; collectively, that is, the economics of *knowledge*. He illuminated an inescapable tension between creating incentives for the production of *new* ideas and maintaining incentives for the efficient distribution and use of *existing* knowledge—the social choice that creates what we call intellectual property.

Managing the tension between these ends—furthering the growth of knowledge while ensuring that its benefits are widely shared—is a responsibility of government every bit as important as monetary and fiscal policy. If the intricate system of incentives to create new ideas is underdevelope society suffers from the general lack of progress (most of all, the poor). So, too, if those incentives a too lavish or too closely held.

Grasp that, and you understand the punch line of the story that this book has to tell. Chances are that intuitively you understood it well enough already

But with the publication of "Endogenous Technological Change," Romer won a race of sorts, a race within the community of university-based research economists to make sense of the process of globalization at the end of the twentieth century, and to say something practical and new about how t encourage economic development in places where it had failed to occur. That there had been a race a all was apparent only to a relative handful of persons, those offering competing explanations of events. That there might exist a "right answer" to the riddle of economic growth, or even that a riddle existed at all, was denied by many people and probably doubted by most.

Yet within a few years the issues attending the post–World War II growth in the wealth of nations had been clarified and, if not resolved, at least reframed in the formal language of technical economics. The basic choices had become clearer than before. The contribution of the growth of knowledge had been broached in a way that permitted its analysis. A new emphasis had been placed o the role of institutions. And a secure role finally was assigned to that long-neglected figure (at least i economics classrooms), the enterpreneur.

"Romer '90" (to use the article's citation shorthand) doesn't fit our conception of a classic, to b placed on the shelf alongside the works of other great worldly philosophers. But it *is*—for reasons tha are relatively easy to explain.

CONSIDER THE BASIC building blocks of economic theory—the familiar "factors of production." They are described in the first chapter of almost any elementary economics text. For three centuries these most fundamental analytic categories of economics were land, labor, and capital. Land was shorthand

for the productive capacities of the earth itself, its pastures and forests and rivers and oceans and mines. Labor, for the diverse efforts, talents, and simple motive power of working men and women. Capital, for the equipment that they employed and the structures in which they work and live, not jus

Capital, for the equipment that they employed and the structures in which they work and live, not just the goods themselves, but financial assets of all sorts representing command over these goods and th services of labor. These categories had been worked out during the seventeenth century, when the expanding global economy gave birth to modern capitalism. They referred to familiar, everyday thing and seemed to leave nothing out. They enabled economists to argue about who should produce what goods and for whom, about work relationships, about the determinants of the size of the human population, about which responsibilities properly belonged to government and which were best left to markets.

From the beginning, some circumstances in the human condition were simply taken for granted. The extent of knowledge was one. Human nature itself, expressed as tastes and preferences, was another. These were "givens," not necessarily thought to be unchanging, but considered to be determined by noneconomic forces—a simplifying custom in technical economics that went back at least to the nineteenth century and John Stuart Mill. These background conditions were, in modern parlance, treated as being *exogenous* to the economic system. They lay outside the model, treated as a "black box" whose detailed internal workings were to be willfully ignored. Exogenous to her concern is what the waitress means when she says, "It's not my table."

Certain loose ends arose as a result of this way of dividing up the world, especially a well-known family of troublesome effects that were filed under the heading of "increasing returns" to scale. Decreasing returns to additional investment were a familiar topic in economics. After all, even the richest vein of coal plays out. The first barrel of fertilizer does wonders for a plot of land; the tenth only burns the crops. Decreasing or diminishing returns simply mean that you pick the low-hanging fruit first, and that you collect less fruit for the same amount of effort over time. It means that your costs slowly rise.

Increasing returns are just the opposite. They set in when the same amount of work or sacrifice produces an *increasing* quantity of goods or, to turn the definition on its head, when your average costs fall and keep falling with the number of articles produced. Pins are the example usually given, after a famous passage by Adam Smith about the gains from specialization. But Smith's story of falling costs seemed to be only about the benefits of the subdivision of tasks. Obviously there were limits to that, too.

Throughout the nineteenth century, increasing returns were considered to have to do mainly with the output of machines—the printing press, the mechanical loom, the steam engine. Gradually it was recognized that increasing returns were present any time there was little or no additional cost to adding a customer to a network—railroads, electricity, telephones, for example. Increasing returns (falling costs) in these and other industries were so destructive of the ordinary forces of competition that such businesses soon were declared to be not just monopolies but "natural monopolies," markets whose fundamental properties led inexorably to a single producer of goods with no close substitutes, and whose conduct in the absence of competitive forces necessarily would have to be overseen by government.

Economists who came after Adam Smith never were very comfortable with the phenomenon of increasing returns, of steadily falling costs. It ran counter to their most basic intuition—that scarcity was the fundamental problem, that the human race was forever running out of something, whether land, or food, or coal, or clean air. Falling costs violated this understanding, and they were much less consistent than rising costs with the mathematical tools that they employed to describe and analyze the effects of competition. Monopolies were understood to be exceptions to the rule. Situations in which producers were free to set their prices, rather than have them set by competitive forces, were special cases of "market failure," to be mentioned in footnotes, left out of the argument altogether, while economists focused on competition.

So the problem of increasing returns was put aside for some later date. Economists finessed it

So the problem of increasing returns was put aside for some later date. Economists finessed it, introducing concepts that seemed to make the contradictions disappear—the convenient assumption, for example, that overall returns to scale might generally be neither increasing nor decreasing but *constant*, that effort and output forever would increase only in direct proportion to one another. In establishing this assumption as a mostly unconscious mental habit, growing formalization played a central role.

With the addition of each new wave of technique, from literary economics to syllogism in the eighteenth century, from syllogism to calculus in the nineteenth, from calculus to set theory and topology in the twentieth, the status of increasing returns became more problematic and obscure, especially after the triumph in the 1950s of formal models of the economy as a whole.

IN THE LATE 1970s and early 1980s, the situation began to change. The developments in growth theory with which this book is concerned unfolded mainly in Cambridge, Massachusetts, and Chicago, very far indeed from the controversies over "supply-side economics" that garnered headlines in New York City and Washington, D.C. in those days. A handful of graduate students at the University of Chicago, the Massachusetts Institute of Technology, Harvard University, and Princeton University discovered for themselves that the blind spot in the vocabulary and analytic framework of economics, once small had with the passage of time (and increased abstraction) become enormous. They set out to make formal models of the phenomena that led to increasing returns. And in fairly short order they succeeded.

For a time these matters were no more earthshaking than conversations among the young economists and their teachers, their spouses, friends, and competitors. Excitement slowly spread throughout the discipline. New ideas about subjects such as novelty, variety, and market power were mapped into the tapestry of economic thought—first in the subfield of industrial organization, then in trade, then in growth, then back into industrial organization. New models were applied to policies for population, education, science, entrepreneurship, trade, antitrust, and cities, not to mention the familiar macroeconomic concerns of monetary and fiscal policy. These studies meshed with the new emphasis on political economy. They turned rapidly to the political and economic institutions that accommodate change—arrangements that were themselves a kind of knowledge. For a few years in the early 1990s, almost everybody in economics had something to say about the new ideas regarding increasing returns.

These developments, which would otherwise remain quite obscure, have the advantage of having been a deeply human drama as well, in which present-day heroes in certain ways personify the generations of modern economics—Robert Solow born in 1924, Robert Lucas born in 1937, and Paul Romer born in 1955. The story of how knowledge was left out of economics for so long—and why, in some quarters, it is *still* met with a reluctant reception—makes a pretty good yarn by itself.

For the significance of "Endogenous Technological Change" becomes clear as soon as soon as the paper's key equations are translated into everyday language. Romer's 1990 paper divided up the economic world along lines different from earlier ones. Overnight for those who were involved in actually making the intellectual revolution, more slowly for all the rest of us, the traditional "factors of production" were redefined. The fundamental categories of economic analysis ceased to be, as they had been for two hundred years, land, labor, and capital. This most elementary classification was supplanted by people, ideas, and things.

People, ideas, and things. This phrase isn't in the textbooks yet. It isn't widespread in the literature. But once the economics of knowledge was recognized as differing in crucial respects (nonrival, partially excludable goods!) from the traditional economics of people (human beings with