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RPMs, or Revolutions by the Minute[1]

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"Revolutions Per Minute", of course, exaggerates. After years of battering by headline and sound bite, it only *seems* we need tachometers to measure ongoing rates of revolutionary change. Nonetheless, the continuing technical changes, as well as their political, economic and military consequences, have already been genuinely revolutionary. Not media hype. They change things by many orders of magnitude.

One technical change didn't *need* hype -- the one that gave the Cold War just ending its other name: The Atomic Age. Nuclear fission and fusion completed the possibilities of releasing energy from the atom. Together they multiplied the destructive energy that a single weapon can release one million-fold and the area it could obliterate indiscriminately about ten thousand-fold. Fission and fusion announced themselves suddenly and unmistakably: Hiroshima. Nagasaki. Bikini. Eniwetok. The wartime annihilation of a whole city or the sinking, in what was just a test, of an entire coral island was hard to miss. A glimpse of the apocalypse.

Yet the less sudden continuing changes that make up the Information Revolution dwarf in significance these two spectacular leaps in nuclear technology. They transform military security, politics within and among nations, the costs and efficiency of market transactions and economic growth. The technical changes are larger, and their effects more ramified, more closely interconnected and much more important than the changes worked by fission and fusion.

I.

The advances in microelectronics and optics that *underlie* the Information Revolution have been happening quietly over a long period. They happen at an exponential rate small in any given year compared to the big leaps in nuclear energy. But they've been accumulating to much more.

The number of transistors on a chip has increased by a factor of 100 every ten years. In 1989, chips the size of a child's fingernail contained over a million transistors, performed many tens of millions of instructions per second, and had reduced costs per

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operation a million-fold in the preceding thirty years. Such superscalar chips are being used to design new chips and so accelerate this exponential rate of growth. In a decade, Intel expects a chip with a billion transistors. All this speeds the acquiring, processing and transmission of information.

One nice thing about the Information Revolution is that something *good* -- the spread of knowledge, which has no limits -- is increasing at an exponential rate. That contrasts with the typical doomsdays announced, one after another, by natural scientists: the Apocalypse Of The Month: Silent Spring, the Population Bomb, the Exhaustion of Fossil Fuels, the Coming Ice Age, Nuclear Winter, Global Warming, and others. Several doomsayers have gained celebrity by announcing in quick succession Nuclear Winter, the Coming Ice Age, and Global Warming -- without embarrassment, without troubling their primetime hosts, and without damage to their celebrity status or their academic careers.

In such predictions of global disaster, only something *bad* increases exponentially. The good, countering factors run against a fixed limit -- or increase only arithmetically -- or at a lower exponential rate.

A characteristic problem for policy choice raised by current doomsday prophecies is that the predicted catastrophe may be distant in time but is always vague and highly uncertain. The actions urged are immediate, costly, risky -- sometimes desperate.

The grandaddy of all apocalyptic prophecies, of course, was The Inevitability of Nuclear War. The argument ran that a global holocaust was inevitable unless politics within and among nations changed drastically and immediately: The arms race would multiply nuclear weapons exponentially, and the probability of war in any given year (unconsciously assumed to be fixed or rising) would cumulate steadily until the holocaust was nearly certain.

The argument had gaping logical holes. Yet it was made by some splendid physicists, Russian as well as Western. And by at least one great -- or once great -- mathematical logician, Bertrand Russell.
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The fathers of the Nuclear Revolution wanted the awful prospect of a nuclear holocaust to shock political rulers, including Stalin, into an end to secrecy and a large surrender of sovereignty. The stark choice was One World -- an open world -- Or None. They believed that civilian applications of nuclear energy would make that world one of plenty; that they would revolutionize industry and transport and that world politics would be transformed. But the release of energy from the nucleus meant only a revolution in warfare, not a revolution in transport and industry. Nor in politics.

Exaggerating the civilian benefits made Stalin less willing to give up national civilian programs. Political openness is simply incompatible with a Communist dictator-

ship. The huge destructive potential of the atom only prompted an increase in secrecy -- the building of some 200 secret Soviet cities.

II.

For a democracy, the ability to destroy a huge area indiscriminately is usable only in desperate circumstances. And the more indiscriminate the destruction, the less likely it is to be used. This is especially so if one is responding to an attack not on oneself but on an ally, and destruction is likely to be reciprocal. Academic babble about suicide pacts couldn't change that. It *did* slow the application of information technology to increase precision and to reduce the yield and indiscriminateness of nuclear weapons. But in any case, the precision revolution had its most important application to *non*nuclear force. Desert Storm demonstrated this brilliantly, with missiles that destroyed the contents of a military structure while leaving its walls standing and nearby buildings untouched. And even more by the rapid destruction of artillery, tanks and other heavy combat equipment on the battlefield -- until we stopped.

Desert Storm exploited only *some* of the advances in the precise application of nonnuclear military force that had been made since the late 1960s. Because we had been preoccupied mainly by a massive invasion through the center of Europe that would quickly turn nuclear, and with monitoring agreements on strategic arms, we were less adequately prepared to use developments in information technology such as small, inexpensive, unmanned air vehicles that can provide timely information and communications in the theater of battle. The Israelis and the Egyptians had more of these than we did. The Egyptians had *stealthy* unmanned vehicles.

To benefit fully from miss distances of a few feet, targets need to be located even more accurately, and we have to know what small part of a target is critical for its function. Also, we have to know how direct immediate damage to the target is related to delayed and indirect system effects on other military targets and on the civilian systems we want to avoid harming. Politically useable force needs clear-cut military aims, and clearer political aims than those of the Gulf War Coalition.

Still, we can get one relevant measure of the change over the last 50 years in our ability to use nonnuclear force precisely if we compare the F-117A Stealth bomber attacks in 1991 with the British Bombing Offensive against Germany in 1941. The British found they had missed their targets so completely that they would have to abandon precision attacks and resort to huge incendiary raids against entire cities. The F-117A attacked and hit targets in Baghdad at night that were more heavily defended and at greater range than the targets in the 1941 Offensive. That comparison suggests that the cumulative information revolution has had a greater effect on our ability to destroy a military target that we aim at than the fission and fusion revolutions combined. It has shrunk the area of uncertainty as to where a bomb would hit by a factor of a hundred million. This is

four orders of magnitude more effective than the ten thousand-fold increase in the area destroyed by nuclear brute force. Nuclear weapons, like the huge bomber raids that destroyed Dresden by blast and fire, make up for incompetence in aiming at a target like a missile factor or a military communications building by filling the huge area of aiming error with destruction. In the process, they are likely to destroy a great deal that is not aimed at.

For a democracy, however, the ability to apply military force selectively -- and to hit only what one is aiming at and avoid hitting anything else -- has an even larger political and strategic importance than an increase merely in destructive power. We can then preserve what we should want to preserve: Civilians that do us no harm, irreplaceable cultural monuments, and friendly forces. If not, another information development -- instant satellite transmission to home TV screens showing the outcomes of attack -- would make it essential in order to maintain allied and domestic support.

III.

Not only arms, but arms control have been affected by the Information Revolution. In the aftermath of Desert Storm, for example, attempts to find and destroy Iraqi nuclear facilities have displayed the vacuity of relying exclusively on satellite photography to monitor agreements limiting weapons of mass destruction. It offers strong hints of how ground inspection, if it were supported by the wide dispersal of mobile shirt-pocket-size transmitters using communication satellites, might improve matters. Important given the imminent spread of such weapons and the means to deliver them. David Kay, leader of the UN team, was surrounded for four days by Republican Guards intent on keeping him from leaving Iraq with key documents on a nuclear facility. He simply faxed them to the US by satellite. And he had only Radio-Shack-level equipment.

In the future, small, mobile, more advanced computers and communications equipment spread widely in the population will play a key role in economic growth. They will also make it safer for potential whistle-blowers, not only official inspectors. And they will help frustrate the reversal of popular moves towards independence.

Western leaders have tried to keep the Soviet Union together, in part so as to have someone to sign arms agreements with. Since they failed, they've been trying to make Russia a close equivalent. But it was the *disintegration* of the Soviet Empire, including the Soviet Union -- not arms control -- that reduced the arms in the center of Europe and the danger of invasion which had preoccupied us.

Secretary Baker has said that for Russia to eliminate nuclear missiles -- even those missiles aimed at us -- would "undermine the whole concept of deterrence" -- which is mysterious. We don't say that Germany or Japan or Ukraine needs some missiles to deter us. Some former Soviet republics feel more nervous than Mr. Baker about Russian

missiles as a menace to their independence. They were ready to transfer their nuclear weapons to Russia, but said they had no way of being sure that Russia was actually destroying them. Neither do we. And since the General Staff and the KGB are alive and well and in charge of these weapons, it's not clear that Yeltsin has.

We could have said to the non-Russian republics, whose claim on these weapons is as valid as Russia's, that they had a point. Since the actual destruction of weapons transferred will in any case take years (the General Staff is more eager to get the weapons on their territory than they are to destroy them), we should have encouraged arrangements for all the non-Russian nuclear republics to share in monitoring on the ground the dismantling and storage of weapons. Personal satellite communications in the hands of those interested in enforcing the agreement could then assure a timely warning never feasible up to now.

The example has general relevance for future arms control. With the end of the Cold War, the US has reduced the hair-trigger alertness of its strategic forces. As former adversaries indicate their willingness to enter into more open, cooperative arms arrangements, we can exploit the new technologies to make sure their forces are in a much lower state of readiness, to get warning if they increase readiness, and to have available a range of offsetting readying moves of our own starting from any new level.

IV.

These effects of the information revolution on arms and arms agreements reinforce and are reinforced by parallel changes in worldwide market transactions and growth, and in politics within and among nations. I've dealt with these last two subjects and their connection at some length in "The Fax Shall Make You Free," a talk that I gave in Prague two years ago. Here I can only make a few summary statements.

The Information Revolution is the most powerful engine driving innovation and economic growth, creating world markets, and reducing the costs and uncertainties of innumerable widely separated, individual, voluntary transactions. These innovations have been decentralizing. They have dispersed rather than concentrated the ability to acquire, process and transmit information.

The new technology fits well the view of economics typified by Friedrich Hayek, which sees economic activities as adjusting themselves by responses to signals sent by market clearing prices -- without the need or possibility of a central plan. By improving the operation of dispersed markets, the new technologies improve the operation of the system as a whole.

Moving from dictatorship and full socialism to democracy and free markets was bound to be painful. It's never happened. Disasters are likely. But moving towards

one and not the other may be even harder. The irrationalities of socialist planning led to its breakdown even with the most ruthless compulsion to replace economic incentives. Getting it to work *without* compulsion would be less possible.

On the other hand, the tempting notion -- suggested by the experience of Pinochet in Chile -- that free markets might be introduced more easily by dictators than by a simultaneous move toward democracy is quite doubtful. And Pinochet didn't start from a full socialist economy.

The dictators want to catch up with the dynamic Western economics today. And to attract Western investment. They can't do that without dispersing to their subjects fax machines, modems, copiers, mobile telephones, and a good deal else. That will make it extremely difficult to prevent dissidents from talking to each other and to the outside world -- very hard on any dictatorship.

China is trying to contain its market experiments in coastal enclaves. But these enclaves have been the greatest source of dissent. And, if the experiment is to succeed for China as a whole, decentralized communications -- and their use by dissidents -- will have to spread.

There is nothing, of course, inevitable about these developments. But it seems a good bet that, as Friederich Hayek said, the intrinsic connection between free markets and political freedom will assert itself. And the new decentralizing technologies essential to the modern dynamic growth dictators want will help make it happen.

"May you live in a revolutionary time" is an old Chinese curse. So it may turn out for the old men of Tiananmen. But not for the dissidents.

Commentators stunned by the succession of revolutions in Eastern Europe, by the breakdown of the economies of the Communist countries, by the upsurge of nationalism in the Soviet Union, and by the outbreak of war in the Persian Gulf rather than in the center of Europe -- where proper contingencies were supposed to happen -- have tended to prefix all their comments on these matters by the phrase "Nobody could have predicted that...." That suggests that they have been no wronger than anybody else.

Not so. On each of these subjects, a minority of distinguished scholars persistently differed from the consensus. All such predictions are wagers. But their bets were based on a better informed and better reasoned analysis of the forces at work than the wagers of the majority.

The apocalyptic prophecies are wagers too. Poor bets so far, but there's no *guarantee* that we'll avoid all global catastrophes. The increase in world travel, for instance, raises the risks of a pandemic. Some deadly virus might mutate more rapidly than our ability to devise counter-therapies. The species that survives we may see as a lower order

than mankind. This possibility is plausible enough for us to continue to devote resources to biogenetic research, to resist opposition to testing therapies on animals, and to reserve some skepticism about vague proposals about biodiversity that might cripple such research. Some species we may *want* to endanger.

There is a lovely, well-known passage in the *Pensees* of Blaise Pascal, the seventeenth century probability theorist and philosopher. It's about the condition of man -- his evident fragility and vulnerability by comparison to some other species -- killed by a vapor, a drop of water. "Man," he wrote, "is only a reed. The weakest in nature." But, he added, "a thinking reed."

As we leave the apocalyptic age, a homely paraphrase might run: Man, like all other species in nature, faces daunting odds. But man is the species that can use information, reasoning and insight to improve the odds.