Thinking Long-Term: Economic or Civilizational Analysis?

Toby E. Huff

The Lichtenberg Kolleg Georg-August-University Goettingen and Harvard

In this paper I want to bring together several different stands of history and theory, to suggest that what some economists have described as "long waves" are not only driven by technological surges as economists from Schumpeter to Carlota Perez have suggested, but that the underlying cultural and institutional dynamics are driven by what I shall call "civilizational dynamics." That means both that major economic surges are not so much generated by standard economic forces (however described), and that such dynamics sharply delimit what is possible in other civilizational settings. In other words, all the waves of techno-economic revolutions – five (5) is the number identified by Chris Freeman & Perez[1] -- are a product of the dynamics of Western civilization.

Much of what shall say here will be seen as politically incorrect so I hope that readers (and auditors) will remember that I have only recently become a "Europeanist", and that I spent the previous several decades as a student of (and traveler to) the Muslim word and Asia. Consequently I have Muslim and Asian friends around the world and do not intend to denigrate their cultures or aspirations. Several implications flow from the position I set out in the first paragraph: 1) the currently rapid economic development of China, Asia and India is mainly a product of spillovers generated by the current Information technology revolution of the late 20th century, not mainly by indigenous economic dynamics independent of those spillovers.[2]

[1] Chris Freemans and Francisco Louca, *As time Goes by. From the Industrial Revolutions to the Information Revolution* (Oxford, 2001); Carlota Perez, *Technological Revolutions and Financial Capital. The Dynamics of Bubbles and Golden Ages* (Cheltenham, UK: Edward Elgar, 2002).

[2] A general overview of capital flows accompanied by knowledge and technology transfers: Michael Spence, *The Next Convergence. The Future of Economic Growth in a Multispeed World* (Farrar, Straus, Giroux, 2011; and more technical evidence, Zhigang Tao and Susheng Wang, "Foreign Direct Investment and Contract Enforcement," Jour. Comp. Econ. 26 (1998): 761-82.

Second, given the indispensable *cultural and institutional* conditions that have existed only in the Western world for more than the last 300 years, it is very unlikely that either China or India will be at the center of any equivalent techno-economic paradigm in the future of this century.

Third, the focus of attention should not be on which country, the United States, Germany, Japan, Brazil or China is presently experiencing the highest rate of economic growth, but on larger forces and institutional dynamics that make economic and technological advance possible. I think economists have shown that over any extended period of time , measures of economic growth rarely favor the country with the fastest rate of growth in the past economic cycle. It is like stock-picking and mutual fund managing in which one manager excels for a relatively short period of time and then falls back to average or worse.

For the purposes of my paper it isn't terribly important how we define "civilizations;" but in order to make this notion a little less fuzzy, I prefer to define civilizations as social and historical entities that are generally composed of two or more societies or peoples (i.e., 2+n subunits) who share (or have shared) certain religious, legal, and metaphysical principles that give these entities a symbolic coherence. They do not have to have a linguistic unity and generally do not. But it is decisive that these underlying religious, legal, and philosophical principles spread beyond local, regional and linguistic boundaries which is why we refer to these entities as "civilizations" in the first place.[3]

Europe is the best example of such an entity with all its contrasting nation-states, its many ethnic and religious groups, and of course its polyglot mixtures. Despite wars, upheavals, revolutions, fascist takeovers, and economic booms and busts, this entity has somehow persisted-- and led economic, scientific and technological development around the world for centuries.

We may juxtapose this entity to China, the Muslim world, and India as contrasting civilizational entities. Japan is a bit of an outlier and anomaly, and our aspiring civilizational framework can't solve all problems.

In order to understand why my claims (of the first paragraph) maybe so, we need to review (and possibly rethink) the cultural and institutional history of the West starting with what I shall call "the Revolution of

[3] These technical issues are discussed by Benjamin Nelson in, *On the Roads to Modernity: Conscience, Science and Civilizations*, edited by T. E. Huff (reprinted: Lexington Books, 2011).

the Middle Ages." But first I need to insert a textual footnote about differences between economists and sociologists regarding a common view of "institutions" used by economists.

Institutions

Whereas economists tend to look at any social or legal rule as an institution, sociologists and other social scientists view institutions as large structures that solve major societal problems, such as the family, the polity, the military or perhaps the stock market. From an economist's point of view, the narrower focus on *rules* and their change makes perfect sense: any small change in the rules of economic competition, new taxes and so on, will result in new distributions of money, wealth, and poverty.

But from a sociological point of view, however, it is important to stress the thought that institutions are social structures created when ideas are translated into roles and norms. For those norms and role expectations establish guidelines for everyday action. They create normative standards against which appropriate conduct can be judged in the everyday sense of such judgments. But there is a larger sense of normative structuring when these legitimating standards for everyday conduct become the basis for *legal* action. So if we reverse this train of thought, then we can see that legal structures are institutions that set the standards for very long term patterns of human behavior. And it is just those long term consequences of these social and legal norms that I want to focus on here. Institutions as I use the term here are not minor rule stipulations but larger constellations of social engineering and that cannot be so easily changed by a simple act of town counselors or parliamentarians. Institutions in this sense are rooted far more deeply in the culture and everyday assumptions of people than simple expediency or monetary utility.

Furthermore, I will suggest that the *legal* and social revolutions of the Middle Ages created a whole new set of institutional arrangements, and those new structures, set the stage for the rise of the West. The universal significance of those changes we are still witnessing, even if some writers imagine a "decline of the West."

Rethinking Legal History

Any broad evaluation of the social, legal, and political reconstruction of Western Europe that took place in the twelfth and thirteenth centuries will show that it witnessed sweeping legal reforms, indeed, a revolutionary reconstruction, of all the realms and divisions of law-- feudal, manorial, urban, commercial, and royal law -- and therewith the reconstitution of medieval European society. It is also true that neither Islamic law nor Chinese law went through any such major legal reform before the 20th century. Nor did those legal systems ever recognize such a multiplicity of competing jurisdictions as Europe did.

Let me also say that there is a fairly significant consensus today about this legal revolution and readers of my earlier book[4], as well as Jan Luiten van Zanden's, *The Road Long to the Industrial Revolution,* will find familiar themes in my sketch. However, my orchestration of these historical facts lead to a somewhat different historical and theoretical consequences.

In any event, it is this great legal transformation that laid the foundations for the rise and autonomous development of *modern science,* but also the *rise of parliamentary government*, the foundations of what we know as *due process of law*, the very idea of *elective representation* in all forms of corporate bodies, the *legal autonomy of cities and towns*, and a vast array of additional legal devices unique to the West. This is a vast and potent cultural legacy that I believe lies behind the scientific, technological, and economic ascendancy of the West that was at the same time tied to the belief in constitutional democracy.

At the center of this development one finds the legal and political principle of treating *collective actors* as a whole body a corporation (*universitas* in medieval Latin) . The emergence of corporate actors was unquestionably revolutionary in that the legal theory which made them possible created a variety of new forms and powers of association that were unique to the West. Furthermore, the legal theory of corporations brings in its train organizational principles establishing such political ideas as *constitutional government*, *consent in political decision making*, *the right of political and legal representation*, the *powers of adjudication and jurisdiction*, and even the power of *autonomous legislation*. Aside from the scientific revolution itself, and perhaps even the Reformation, no other revolution has been as pregnant with new social and political implications as the legal revolution of the European Middle Ages. By laying

[4] T Huff, *The Rise of Early Modern Science: Islam, China and the West* (Cambridge UP, 1993/ 2003).

out the conceptual foundations for new institutional forms in legal thought, it prepared the way for the two other revolutions-- the scientific and economic.

I need to fill in a few details here because there are scholars (some historical economists included)[5] who think that the idea and practice of the "rule of law" was invented in the 17th or 18th century. However, the story really begins in the 11th and 12th century when the Roman *Corpus Juris Civilis* that had been established by Emperor Justinian back in 534 A.D., was rediscovered by an Italian monk. This discovery occurred around 1000 AD and that discovery jolted legal scholars into action. At first they did not understand it and so commentators known as the Glossators set about writing marginal commentaries, perhaps correcting grammar, explaining the new conceptual terminology, but most of all, trying to master the 2000 pages of this extraordinary legal system.

To shorten our story, let me just say that by 1200 these legal scholars had become a distinct literate class of specialists, had mastered the Roman legal corpus, and in a great many ways, modified, systematized and transformed it into a new *legal science* which was now to be taught for the first time in universities across Europe. The initial leading center of this new science of law was in the university at Bologna. These legal scholars were known as the civilians, that is, the ones who taught the new science focused largely on *secular* issues and causes.

But at the same time, a scholar and monk by the name of Gratian took it upon himself to rethink the whole great amorphous body of laws then known to him, and to create what he called "A Concord of Discordant Canons"-- first issued in 1140. Here the word *canons* simply means "rules," but especially rules that had been adopted by the Church, which in a very short period of time became the standard legal text used all across Europe, though the Church never promulgated it officially.

What Gratian had done was to collect legal texts from Church councils, papal letters, the writings of Church Fathers, passages from the Bible, and host of secular sources such as Roman and

[5] Douglass North and B. R. Weingast, "Constitutions and Commitment: Evolution of Institutions Governing Public Office in 17th Century England," *Journal of Economic History* 49 (1989): 803-32; now followed by D. Acemoglu and Robinson, *Why Nations Fail…*

German law. His great effort was designed to point out the contradictions in these legal rules, to remove them, and to find the underlying legal principles that ought to prevail.

So now Europeans had *a new legal science* based on new texts, all of which became what legal historians call the *ius commune*, the common law of Europe that began to spread from south to north, to Britain as well as Scandinavia. Moreover, law students across Europe now had to learn both the Canon Law and Civil law, because (1) the Church universal had courts all across Europe, and (2) lawyers specializing in the civil law might be called upon to defend a case in an ecclesiastical court.

Here then we have the first and second legs of this medieval revolution. First we have a *new legal science* that was to be taught in the universities, and applied in the courts across Europe, in both secular and ecclesiastical courts.

Second, the medieval legists recognized the legal rights of collective actors, that is, legally autonomous entities, sometimes called "fictive personalities." Among these we find cities and towns, charitable organizations, professional associations of doctors and lawyers, as well as merchant guilds-- all of whom *could create* their own rules and regulations. These new entities were treated as *collective individuals* and had a whole new bundle of right: the right to own property, to sue and be sued, to make their own rules and regulations, i.e., to act as legislative entities. Such entities had the right to be represented by attorneys in courts, and before the king's court regarding taxation.

Furthermore, these entities were said to be governed by the principle of, "what concerns all should be considered and approved by all" -- a Roman maxim.[6] While today we think of corporations as primarily significant for commercial enterprises, their original impact was in *public law*, where their presence radically transformed the whole basis of political and constitutional life in Europe. For it was the presence of these new entities that established the foundations for *parliamentary democracy*. Indeed, the first European parliament was founded in

[6] See Gaines Post, *Studies in Medieval Legal Thought* (1964); and Berman, *Law and Revolution* (Harvard UP, 1983)

1258,[7] and tracing out that whole rise of parliaments across Europe from the 13th century should be another chapter in this revolutionary narrative.

Third-- and this may be the most overlooked aspect of legal history that has been missed in the social science literature-- the canonists and civilians established new principles of *due process of law* that applied to all individuals who were involved with legal proceedings. By the end of the 12th century this new system had been formally articulated as the *ordo iudiciarius.*[8] According to this legal doctrine (which was established in court cases and Papal decretals), every trial must involve a *plaintiff and a defendant, advocates for those two parties, the appearance of witnesses, the presence of court recorders such as clerks, proctors and notaries who record the names of those present at the trial,* what each person said, and if written evidence were presented, it too would be redacted into the court record. Again, this was established legal procedure by the end of the 12th century.

In addition, the procedure established the right of any accused person to be notified of the complaint, the right to appear in court and testify, and, above all, to be represented by a legal expert. Defendants had the right to designate a legal representative who could speak authoritatively for the defendant whether or not he appeared in court.

By 1200 it was firmly establish that anyone appearing in a court could elect to have legal assistance and was well advised to do so. But if he did not do so he was forewarned, as one writer put it in 1169,

> *If someone is brash enough to presume to rely on his own devices even though he is inexperienced and does not wish to have an advocate, let him do so. Everyone is free to muck up his own case*[9]

---

[7] Harold Berman*, Law and Revolution. The Formation of the Western Legal Tradition* (Harvard, 1983), p. 526; and J. Strayer, *On the Medieval Origins of the Modern Stat*e (1970).

[8] Among others see K. Pennington, "Due Process, Community, and the Prince in the Evolution of the Ordo iudiciarus..." (1998); James Brundage, *Medieval Canon Law* (London: Longman, 1995): 205.

[9] Brundage, *The Medieval Origins of the Legal Profession*, p.152.

Here then we have the clear outline and details of **due process of law**, assumed to be universal, that must be applied in all legal proceedings-- all set out by the end of the 12th century.

But -- fourth-- this process went even further toward the establishment of additional legal principles that applied to the Prince and Pope alike. The most important case establishing that these principles applied to the Prince as well as ordinary citizens concerned King Henry of Luxemburg and Robert of Naples. In 1311 King Henry moved to be crowned Emperor of the Holy Roman empire and in doing so intended to displace Robert of Naples and his kingdom. In the process Henry condemned King Robert, declaring him to be a traitor and an outlaw to the Empire. Pope Clement V did not agree with these declarations and tried to mediate between the two parties.

Luckily-- or unluckily-- Henry died (in 1313) before he could move to displace Robert forcefully; but Pope Clement V stepped forward with legal opinions curtailing such presumptuous condemnation of an adversary. The Pope solicited opinions from the best legal scholars and all of them averred that the *right of self-defense*, both physical and legal, was a *right* granted by *natural law* and hence it could not be taken away. Hence King Henry's rulings were without legal merit and were annulled. Furthermore, Pope Clement went on to issue several more legislative rulings, clearly stating what due process of law entails and how it **must not** be abridged. In his final ruling, indeed a constitutional document called *Saepe contingit,* he established these principles, which of necessity must be upheld by the Prince. Legal scholars have concurred that this legal ruling of the very early 14th century was "the most important single piece of medieval legislation in the history of summary judicial procedure."[10]

In word, by the opening of the 14th century, European law had established legal principles restricting the actions of the Prince, but not only that, the Pope. The principle that the Pope too is subject to natural law and may not abridge a defendant's right of self-defense was established in a notorious case involving the Medici's and the attempt of the Pazzi family to eliminate them

---

[10] Stephan Kuttner, "The Date of the Constitution "Saepe"... *Melanges Eugène Tisserant* IV (1964): 427-452, p. 427. Technically, the ruling concerned "Summary proceedings" which are special proceedings held in unusual circumstances, possibly entailing threats of violence and or public harm.

violently. The result was that Pope Sixtus IV-- who had condemned Lorenzo d'Medici without a trial-- had to back down while acknowledging that, just as Adam of the Bible had to respond to God's summons to judgment, so too "neither Pope nor Prince could dispense with this part of the judicial process because no one can ignore a precept of divine law."[11] In other words, the earlier legal principles that restricted the actions of the Prince applied in the same way to the Pope. Neither he nor the Prince could issue summary judgments without actually holding a trial.

Now in recounting this legal history I do not suggest that the people of Florence in the 15th century were particularly law abiding-- they most definitely were not. Nevertheless, a precedent had been established and future rulers who wished to be regarded as lawful occupants of elective or appointed office had to abide by such rules. Of course it took time for the rule of law as we know it to become widely established; nevertheless, the institutional apparatus had been constructed and the process had been launched all across Western Europe -- unlike other parts of the world. And let us not forget that the lords of England forced the King to submit to the *Magna Carta* which, likewise, restricted his sovereign powers and also required the establishment of a jury system.

Finally, I have before me a list of legal innovations in the merchant law that fills nearly a page and a half that you can check out on p. 394 of Harold Berman's, 1983 book, *Law and Revolution. Here a just a couple of them---*

But given the limits of time I must skip over them these innovations in order to speak about the importance of the universities and the scientific revolution. I have spelled out this process before in books and articles but I suspect that many social scientists undertaking comparative research forget this crucial history-- which once again, sets off Europe sharply from other civilizations around the world.

Universities and the Scientific Agenda

---

[11] This is the judgment of the 15th century legal scholar Francesco Accoli, said to be the greatest legal scholar of his time; as paraphrase by Pennington, *The Prince and the Law. Sovereignty and Rights and in the Western Legal Tradition (Univ Calf. Press, 1993), p.188.*

As we all know, the universities of Europe were a byproduct of the legal revolution of the 12th century. Accordingly, they had no legal or functional counterpart outside of Europe in the 12th and 13th centuries. This was so because no other legal system recognized legally autonomous entities that could make up their own rules and regulations.

Secondly, because the universities of Europe institutionalized the study of the natural books of Aristotle, that is, instituted a whole curriculum of naturalistic studies, they were singularities of higher education across the world. We have seen that the universities, especially those in Italy, were at the forefront of legal studies from the 12th century onward. But when the universities emerged in the 12th century European scholars refocused the curriculum of the universities around the three philosophies—natural philosophy, moral philosophy, and metaphysics. Then they placed at the center of this new curriculum the natural books of Aristotle. These included his *Physics, On the Heavens, On Generation and Corruption, On the Soul, Meteorology, The Small Works on Natural Things*, as well as biological works such as *The History of Animals*, *The Parts of Animals, and The Generation of Animals*. It is with these books, Ed Grant observed, that we find "the treatises that formed the comprehensive foundation for the medieval conception of the physical world and its operation."[12] This was indeed a core experience that was essentially scientific. Put differently, the Europeans **institutionalized** the study of the natural world by making it the central core of the university curriculum.[13]

The point I have made recently is that the universities *inculcated a spirit of scientific inquiry* -- of intellectual curiosity-- that was to persist all the way to the present, while conversely, that same spirit of innovative inquiry did not take hold outside of Europe.[14] For me the acid test of this proposition was the invention of the telescope by Dutchmen in 1608. Just as soon as this invention appeared, people like Galileo, but not only he, quickly saw its importance for astronomical discovery. It was in fact a "discovery machine," though of course it had to be

---

[12] Edward Grant, "Science and the Medieval Universities," in *Rebirth, Reform, and Resilience*, p. 78.

[13] I have spelled this out more in *The Rise of Early Modern Science: Islam, China and the West* (Camb. UP, 1993/ 2003).

[14] Huff, *Intellectual Curiosity and the Scientific Revolution. A Global Perspective* (Camb. UP, 2010).

constantly improved and focused on new astronomical phenomena, which is what Europeans did throughout the 17th century as the scientific revolution unfolded.

But then, we ask the question, what if the telescope were taken to other parts of the world, to China, India and the Ottoman Empire in the early years of the 17th century? As I have spelled out elsewhere, nothing happened. Neither the Chinese (with lots of tutoring by the Christian missionaries), the Mughals, nor the Ottomans found the telescope to be particularly useful as a scientific instrument. It arrived in all those places between 1615 and 1630, but none of the telescope-users outside Europe made any advances in telescopy or in astronomical discovery.

In short, the transformation of Europe in the 12th and 13th centuries set Europe on a track of economic, scientific, and political development that did not happen elsewhere. Fundamental keys to that path of development are to be found in the revolution of the Middle Ages and the vast new array of legal institutions that it instituted.

Long Waves as Civilizational Productions

Let me now summarize up to here. We can see a rather broad array of institutional structures, unique to the West, emerged, which were fundamentally grounded in its unique legal system. Not just the idea of legally autonomous entities did not evolve outside the West, but our whole *conception of due process of law* rests on entirely different assumptions than can be found in Islamic law or Chinese law. And when we realize that those same medieval legal breakthroughs were responsible for the *evolution of parliamentary democracy and constitutionalism*, we see how steep the uphill transfer of cultural forms to other parts of the world is likely to be—though of course I do not contest the current phase of globalization now going on.

Thirdly, it remains to be seen whether or not developing countries such as China and India can establish Western style universities with guaranteed freedom of inquiry, along with a completely open public sphere that would allow Chinese scientists, for example, to make radical discoveries and insert their technological applications into an economic order free from Party and government control.

Likewise, we know that the scientific revolution occurred only in Europe so that Europeans had ahuge resource of human and scientific capital absent elsewhere. Likewise, the European trajectory of human capital formation through literacy was hundreds of years ahead of literacy standards outside Europe with the consequence that societies and civilizations outside only began catching up in the last quarter of the 20th century.

Now, if we shift our focus to the five (5) outstanding techno-economic revolutions that occurred between the early 18th century and the present which have been sharply defined by Chris Freeman and Carlota Perez, we see that all of them were straightforward products of Western science, technology and culture.

Here they are:

Table 2.1 Five successive technological revolutions, 1770s to 2000s

Technological revolution	*Popular name for the period*	*Core country or countries*	*Big-bang initiating the revolution*	*Year*
FIRST	The 'Industrial Revolution'	Britain	Arkwright's mill opens in Cromford	1771
SECOND	Age of Steam and Railways	Britain (spreading to Continent and USA)	Test of the 'Rocket' steam engine for the Liverpool–Manchester railway	1829
THIRD	Age of Steel, Electricity and Heavy Engineering	USA and Germany forging ahead and overtaking Britain	The Carnegie Bessemer steel plant opens in Pittsburgh, Pennsylvania	1875
FOURTH	Age of Oil, the Automobile and Mass Production	USA (with Germany at first vying for world leadership), later spreading to Europe	First Model-T comes out of the Ford plant in Detroit, Michigan	1908
FIFTH	Age of Information and Telecommunications	USA (spreading to Europe and Asia)	The Intel microprocessor is announced in Santa Clara, California	1971

Now I believe that it is clear that all of these techno-economic revolutions emerged only in the West, either in Europe or the United States (but usually jointly). I would also argue that in the majority of cases these great innovative surges there was (to us) a hidden scientific advance (and breakthrough), and given the absolute dominance of scientific advance by the West since even before the 17th century up to the present, there simply was not any possibility of these great waves of innovation and economic surge occurring outside the West.

Let me unravel the interdependence of scientific and economic progress with these four examples: steam power, electricity, wireless, and the info-age digital revolution.

The development of the steam engine was based on the scientific discovery of the fact that air has weight. A number of Europeans did experiments across the Continent from the 1640s when Torricelli declared that the earth is surrounded by a sea of air whose weight could be measured by the newly invented barometer. This sea of air exerts the same weight (with atmospheric variations) on every square inch of the earth's surface. That is the principle behind the steam engine: steam power in a piston pushes up while the great weight of the air forces the piston down when a vacuum occurs inside the piston cylinder. Already in the 1650s, Otto von Guerike was doing experiments utilizing the concept of work force (and its measurement) connected to the power exerted by the forces of nature in a vacuum (cf Huff, *Intellectual Curiosity*… 2010, chap. 8). Once harnessed, that power would be greater than horses and used everywhere. Without knowledge of those forces of nature it was exceedingly unlikely that anyone could invent the atmospheric steam engine outside Europe.

The second case, *electricity*, is another example of a scientific discovery, one first hinted at by William Gilbert in 1600 with the publication of his book on magnetism. The practical creation and use of electricity took many years, extending to the end of the 17th century when electro-static generators were invented that could produce a short flow of electric charge. In 1706, Francis Hawksbee at the Royal Society demonstrated that with such an apparatus a static electric charge could be transmitted to a vacuum tube, causing the tube to glow, thereby illuminating a moderately sized room so that large print in a book could be read.

Many more scientists and their experiments were needed to fully understand electric charges, the polarities of electricity and the physical mechanisms by which electricity could be reliably generated and transmitted over long distances. But here again, there were no electrical studies outside of Europe during this period; there was no Otto von Guericke, Ewald Georg von Kleist of Germany, Pieter van Musschenbroek of Leiden; no Ben Franklin, no Lichtenberg, Farady and all the others that made the understanding and production of electricity possible.

In one sense, electricity is one of the most fundamental forces of nature and even at the end of the 20th century, modern physics had not completely solved the complex interrelations between the fundamental forces of nature: *strong, weak, gravitational, and electro-magnetic.*

So the invention of *wireless* communication was still another example of a scientific breakthrough without which the old fashion wireless- i.e, radio and TV—would not have been possible.

If, then, we ask, who invented wireless communication and what scientific discoveries made wireless communication possible, the answer points to the late nineteenth century and the work of Heinrich Hertz, German scientist. Working with the implications of James Maxwell's mathematical equations, Hertz discovered that wireless signals are indeed transmitted by certain electric circuits (in 1888). Much more had to be done to get a practical application such as *Marconi* achieved in the 1890s. But he did indeed succeed in making wireless transmission over many surfaces, and across the Atlantic to Cape Cod in my home state of Massachusetts in 1903. The development of radio and television were based on the same fundamental physical principles, leading shortly thereafter to radio communications all over the world.

But let us jump forward to the present and for my *fourth example*: what scientific breakthrough made wireless communication possible as we now know it, that is wireless computers, telephones and all the rest? The answer to that question would be quantum mechanics. What scientists in the 1920s and '30s discovered (along with the very existence of micro-particles such as the electron), is that those particles travel in ways very different from ordinary- size bits of matter, grains of sand and planets. The paths of micro-particles defy the logic of classical physics. Nevertheless, it was discovered that under certain conditions and in certain materials, electrons can be knocked free producing a cascade of miniature communications or energy flows. This was the idea behind the invention of solid state semiconductors, first in 1947, and later when Intel and others produced their microchips—that is computers on a tiny chip of silicon or a similar material.

In this case, the inventors of the transistor (William Shockley, Wm Bardeen and Brattain in 1947) had been studying the latest findings in quantum mechanics[15] (Weiner 1973). The upshot was the invention of the solid state transistor which would have all the functionality of a vacuum tube, and lots more. Once

[15] Weiner, 1973,

perfected (ca.1955-57), it was realized that these solid state devices could hold many transistors. This heralded the invention of the microchip, or a computer on a thumb-size piece of silicon.[16]

To shorten the story, it is only because of all these miniaturized circuits that we can have a computer small enough to fit into your cell phone and lots of other very small devices. The point is, however, that the whole computer revolution in its miniaturized form was highly dependent on the discoveries of quantum physics and a host of other technological breakthroughs. Of course, vacuum tube-based computers were made but they took up whole rooms, needed constant "debugging," and used huge amounts of energy, and so on[17]In a broader sense, the electronic revolution of the 20th century was a product of scientific discoveries whose real roots were in the nineteenth century or very early 20th century; yet their technological applications unfolded only during the second half of the twentieth century. The lesson from this might be that neither China nor India, much less the Middle East, is likely to be the sponsor of a major techno-economic revolution such as this in the twenty-first century. It also probably true that the major scientific and technological breakthroughs that will shape the twenty-first century have already been made. We just do not know which they are.

---

[16] S. Handel, *The Electronic Revolution* (Baltimore,1967):80-92; T.R. Reid, *The Chip*. (New York: Random House,1985/2001).

[17] Paul E. Ceruzzi, *A History of Computing* (Cambridge: MIT Press, 2003.