Software Innovation to Benefit the Business:
Updating Economic Analysis for Information Technology

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Updates to Economic Theory

Imagine that economic theory since Adam Smith has been a series of software releases. Like releases of software, economic theory has started by imperfectly delivering a capability needed by users, only to improve with future versions. Economic theory has been closely related to policy decisions in government and business, making these releases responsive to the "market" for ideas.

Assuming economic theory has gone through many releases, how many releases have there been? What drives a new release? While one can quibble over the version numbers, economic theory does nicely fit into five separate releases. Massive technological change bringing new economic and political organizations has driven these changes. The current wave of technological innovation will, arguably, usher in a sixth release of economic theory. This paper revisits the five previous releases and offers suggestions on the attributes of the sixth release. A case study based on current metrics categories (but not current data) used at Reuters for software measurement and a more detailed discussion of the great depression in the United States will supplement the brief narrative.

The first question one might raise is why start with Adam Smith? Many countries and empires had sophisticated economies prior to the "modern" age. What distinguishes the modern age of economic growth and theory from, say, the Roman period, the Europe of commercial city states, or Chinese dynasties? In terms of economic history, the most dramatic shift appeared in population, with the application of new technologies dramatically increasing global population from a point in the mid eighteenth century.[1] In terms of economic theory, economics became a distinct field of study with Adam Smith and David Hume. These events are related, linked by the emergence of persistent technological change driving what can be called "modern" economic growth.

Many who have studied modern economic growth have recognized the tendency for innovations to clump in certain periods of history.[2] For example, Joseph Schumpeter regarded the process as one marked by the disruption caused by new productive processes, the source of his notion of "creative destruction."[3] Such disruption emerged unfortunately from the creativity driving modern economies. The difficulty presented new opportunities for economic theory, bringing about new "releases" of theory.

Consider the following sets of technological innovations. Each has brought issues and opportunities for business and society.[4]

- Steam engines, Iron and railways
- Steel
- Electricity and Chemicals
- Petroleum/Automobile/Aviation
- Electronics and computers
- Telecommunications and Internet

The releases break down as follows:

1.0 A focus on concept development (to 1770 to 1870)
2.0 Incorporates mathematics and benefits business (1870 to 1920s)
3.0 Incorporates macroeconomic statistics and focuses on public policy (1920s to 1950s)
4.0 Incorporates competing models of state-driven investment for growth (1950s to 1980)
5.0 Embraces the market & computers (1980 to Now)
6.0 Seeks to model factors that encourage innovation

These versions and dates represent a useful approximation. Extending the notion of versions, there have been a number of interim releases between the versions to keep the analysis current without changing the core understanding found in the theoretical approach. Furthermore, like software releases, each release has built on the abilities achieved in previous versions. A new release does not dispense with the previous release but builds on top of it.

What does this have to do with software? Software development represents a key component in the leading economic sectors of this period. While at times one might wish to measure software in isolation from the wider context, all in the industry should recognize the amazing role software now plays in the wider economy. Today software measurement requires reference to wider concerns of economic theory because of the central role software plays in the economy. However, software development is hard to measure in terms of such key indicators as productivity and it is difficult to get the type of valid historical data series familiar to economists. While innovation has been central to economic growth, measurement by economists only imperfectly captures this dynamic process. With the current technological revolution, cycle times have diminished and the impact of innovation becomes apparent not only in long term planning but also under many short-run assumptions, making the measurement strategy used around 1900 less useful now.

Not that previous economists did not understand the importance of innovation, only that innovation did not emerge as a clear theme given many of the measurement strategies pursued to answer the practical questions of the day. So, this is not a criticism of previous economists. Economic history's excitement emerges from the continuous effort to adjust economic themes to confront key issues in business and public life. The practical focus makes economists aware of the new issues and political organizations emerging with each wave of technological change.[5]

This sets the stage for a very brief overview of how the "releases" have dealt with the now crucial question of innovation.[6]

Release 1.0: Concept Development

The first release could easily break into a 1.0, 1.1, and 1.2 as it encompasses three distinct generations. However, in terms of measurement strategies, these early economists did not on the whole set economics on the quantitative path. Indeed, much of the work done by these economists emphasizes political economy and general policy issues. Adam Smith and David Hume focused on the merits of a competitive economy and the drawbacks of a mercantilist economy. Thomas Malthus and David Ricardo, writing a generation later, focused on problems of food shortages and the importance of repealing England's Corn Laws. Karl Marx and John Stuart Mill focused more explicitly on the conditions of labor and the way to bring greater benefit to society; for Marx, the driver emerged from the inevitable battle between capitalism and socialism while Mill became an early advocate of birth control and increased rights for women.

A few key concepts became entrenched during this first release. Above all, economics became accepted as a field for study that could be applied to practical policy. In terms of modeling innovation, however, early economists did not integrate persistent innovation in their theories. With a heavy focus on the limits to growth and the inevitability of conflict, economics became known as the "dismal science" for its worldly focus.

Successful Release v 2.0

Economics took on an increasingly quantitative aspect with the success of marginal analysis that allowed the modeling of microeconomic decisions using mathematical devices such as calculus. As businesses made profit with the use of the new economic tools, the profession of economics established a more secure position, with economic professors often called to give expert testimony to government.[7]

However, the new economic tools, based on short-run assumptions about productivity, only imperfectly modeled economic growth. Alfred Marshall, one of the key members of the "Cambridge School" that would produce so many influential economists (such as John Maynard Keynes) recognized such limitations. In the preface to the eighth edition of his *Principles of Economics* (the standard economics textbook of the day), Marshall explained his view of economics: "The main concern of economics is thus with human beings who are impelled, for good and evil, to change and progress. Fragmentary statical hypotheses are used as temporary auxiliaries to dynamical--or rather biological--conceptions: but the central idea of economics, even when the Foundations alone are under discussion, must be that of living force and movement."[8] Living force and movement were essential to economic growth since the increasing returns from innovation fueled economic growth. Marshall then goes on to predict correctly the "dominion" of differential calculus in economic analysis. Marshall understood this approach did not capture the dynamic nature of economic growth.

While describing this gap between micro-analysis under short-run assumptions and the effort to understand living growth and innovation, Marshall never managed to bridge the gap. What Marshall left was an open requirements database that does not really become

relevant until now, when the short-run assumptions lose their utility because of the pace of change.

Version 3.0: Macroeconomics

Marshall's prediction of the "dominion" of the new economic tools came to pass, in part due to the influence of his students. The next release of economic theory featured more prominently a statistical approach, this time applied to macroeconomic themes. Marshall's vision of economics as "biological" gets lost in the new release. John Maynard Keynes, for one, did not regard his teacher's interest in economic history and economic "biology" as that useful.[9] Keynes would lead a generation of macroeconomists who would use measurement to confront major policy problems of the day.

Governments collect statistics related to taxation. With the rise of the income tax in the twentieth century, national income accounting became a possibility. While originally kept as an artifact of the need to capture income data, national income accounting soon became an integral part of government analysis for managing the economy and war efforts. The government began to hire economists to study national data, taking economics in a new direction. However, the focus on national data sets was not a good way to capture innovation.

The Challenge of the Great Depression

A brief case study of the great depression in the United States highlights the importance of getting the economic theory correct and the damage caused by neglecting the factors that foster innovation. The great depression presented a tremendous challenge for government in the United States. With high unemployment, a collapsing international economy, and stagnant growth, government leaders turned to the professional economists for help. With only highly aggregated statistics available and using the tools of analysis designed around short run assumptions to factor out innovation, these economists set out on a course to help ease the depression.

Their prescriptions, in hindsight, actually served to worsen the depression in the United States. Following prescriptions applicable to other cyclical downturns, national leaders did not understand the structural transformation in the economy that made such measures no longer useful. In short, national policy discouraged the flow of capital into innovative sectors. Rather, investment went to New Deal protected industries that offered few returns. With the stock market unstable, it became rather difficult for innovative companies to secure capital. As detailed analysis of individual secftors has now shown, growth during the depression did occur in certain innovative sectors. However, public policy did not encourage investment to target these businesses, so the leading sectors could not drive general economic growth. Failure to nurture the innovation of growing businesses hurt the economy.[10]

World War II, in the United States, corresponded to the end of the depression. Not that war tends to strengthen an economy; rather, the war encouraged innovation in production

to respond to the crisis at hand. For example, innovative players in the rubber industry managed to take advantage of the War to put in place large-scale production of technological changes that could have been implemented earlier provided a reasonable investment strategy. World War II emerged as a more substantial success for national planners, as national data took on a general meaning related to the health of the economy that it continues to have down to today.

The efforts of the third release, then, focused on analysis of highly aggregated data to address pressing issues while leaving to the side the more complex issue of innovation. The cost, however, of not properly understanding innovation and the drivers of the modern economy, was large. Failure of economic theory can have a tremendous impact on society.

Version 4.0: Competing Models of State Control

The post World War II world soon had the Cold War driving economic and strategic planning for governments. While the Soviet Union went entirely for state planning and control, the United States and other advanced economies opted for a mixture of social welfare control and private industry. Furthermore, these competing models of economic organization found their way to "less developed" regions.[11]

Economic measurement during this period tended to produce the aggregated statistics more useful for politicians arguing for increased aid than for businesses trying to grow. Such misleading statistics led many in the United States in the late 1950s to believe that the Soviet Union had a better economic organization due to the rapid gains in GNP and the success of Sputnik.[12] Such linear thinking failed to take into account the discontinuous and creative nature of innovation.

The focus on general statistical categories also tended to encourage countries to imitate the technology of advanced countries without capturing the innovation that actually drove economic growth. For example, India in the 1950s welcomed suitors from Germany, Britain, the United States and the Soviet Union to help build the steel industry. For Nehru, steel was the stuff that would make India modern. Such a vision only sought to imitate, not to create. The period 1950 to 1980 saw many technologies transferred to advancing countries, but only sometimes did this take off for business benefit.

State driven economies have held a fascination for many, promising the eradication of all sorts of general social ills. However, state controlled economies fail to recognize a central element of economic measurement: the free market determines price, not state bureaucrats. Such a misconception can lead to mismanagement of a national economy, causing tremendous disruption and misery. The ability to accurately understand economic growth and foster innovation are skills critical not only to business success but to national success as well. The importance of such an understanding should not be underestimated. The implementation of state control over markets may well have destroyed markets and discouraged innovation. The Soviet Union may have managed to build the biggest late

nineteenth century steel based economy in the world in the 1950s. While such an economy may have looked great in terms of measurement categories derived from late nineteenth century leading sectors (like GNP growth), The Soviet Union did not build a system to survive over the long term because they destroyed the capacity for innovation.

Version 5.0: The Market Reemerges

With inflation running into double digits and the welfare state under increasing pressure, government leaders became willing to turn to more market oriented solutions to national problems. Collapsing communist economies served as a warning against the promises of state planning. Increasingly, a functioning market providing prices became recognized as a key element of prosperity.[13]

The development of the computer helped to secure the market as a force in international affairs. The application of computer technology to markets made price control more difficult, while offering tremendous arbitrage opportunities for technological leaders. The emergence of a true global field linked with computer technology has made markets very responsive to information.

With substantial economic growth taking place under conditions of rapidly changing technology, innovation's roll in economic development emerges prominently. In the past decade, consultancy has taken hold as companies look for ways to apply innovative technology relying on rented "expert" resources. Consultants have brought a focus on the ability of businesses to absorb change.

Although innovation has emerged with the market focus of the fifth release, measurement strategies still rely on aggregated statistics originally developed to address the concerns of previous eras. Many economists and business leaders recognize the problem with many traditional measurements, such as GDP.[14]

The Future: A Guess and Suggestions

As history involves the ability to understand the key factors leading to change and evolution in the past, the true test of any historical narrative lies in the ability to look forward with a vision more accurate than chance. So, what type of measurement will economic theory accommodate in the coming decades?

Economic analysis will continue to take advantage of the opportunities presented by information technology for the collection and presentation of data. Automated extraction of data will enhance accuracy and allow for more tailored application of measurement data, such as the "dashboard" concept. Consultants will help tailor these new technologies for business benefit.

The central argument of this paper has been that the short-run assumptions made for practical reasons a century ago have lost their relevance for the practical issues of

software measurement because of the importance of innovation in both the manufacture and sale of software. Capturing the factors involved in making a business or group innovative will require a set of measurements used to describe a living organism. The analogy for economics in the coming century will revolve less around mathematical models and more around biological or descriptive use of measurement to capture what Marshall described as “living force and movement.” This is not to say that sophisticated mathematics will become obsolete. On the contrary, just as biological sciences can employ complicated mathematical models, so can the software business. These models, however, will increasingly function as diagnostic and descriptive tools rather than single data points to track.

This approach will require some training and explanation, but is only a shift in outlook already apparent to those in software metrics if not to senior managers demanding to see a productivity metric presented as a line with a healthy upward slope. Those leading metrics programs today increasingly explain the need to "tell a story" with their metrics. In such an environment, data quality emerges as even more important, since the presentation of a number of variables requires high confidence in accuracy. Practitioners of metrics should look, therefore, to rigorous data definition and quality control. Especially useful are "natural artifacts" of the development process: measurements generated as part of the normal workflow.

Example Sample Maps

Practical application of this approach can be found in a few sample maps based on metrics collected from many Reuters groups. The data in the maps was constructed to show "ideal types" of projects, not to reflect actual projects. The numbers have been created as examples, not from real data. These graphs include a substantial number of measurements in the same graph. With a number of metrics presented together, the scale does not always mean the same thing for each metric. In many cases, the percentage indicates the deviation from the mean; 200% means a project has twice the amount of requirements churn compared to the "average" project. For these maps, the shape of the metrics in combination contains the meaning. The graphs are diagnostic tools to indicate the most efficient area to focus process improvement efforts. The graphs, then, are not dashboards or scorecards, but diagnostic tools based on past projects.

A brief mention of the term "project." In this context, project is a rather short iteration of a larger effort focused on discrete deliverables. In most cases, a group will over time begin to produce a number of similar "projects" seeking to improve functionality of the general product by responding to specific needs of customers. These metrics are focused then at a sub-project or deliverable level, not for a huge product.

The first project map (see the presentation slides) comes from a group heavily exposed to market pressures. In a highly competitive market with narrow windows for releasing new products, high requirements change is a part of the management landscape. Such a project shows highly accurate schedule and effort predictability with a few issues in testing coverage and process compliance. In part this is because the project delivery date is

roughly fixed and the development team focuses on maximizing the amount of new functionality in the new release. The defects for this project are more than normally found; however these defects are not "show stoppers" and are in an environment that maximizes the ability of the user to configure the desktop and correct problems, minimizing support costs. A more sophisticated notion of defects is needed in this chart, but defects probably require their own mapping strategy not easily placed into this map. (Indeed, Orthogonal Defect Classification provides an excellent example of the type of map I am describing.) Size estimation is not an important part of the project because the new technology does not make size in itself meaningful to project planners. Rather than try to force collection of an irrelevant metric or insist on a questionable translation to KLOC, no collection is entered.

The prescription for such a group is to focus on efficiencies to be gained in requirements management and the testing process. Focus on size estimation simply to benefit a process model does not make sense for projects of this nature, since the ability to respond to market pressures and genuine changes in client needs drive the business.

The second sample map shows a group that works on projects that must deliver a clear and stable set of requirements. The group appears to follow process rather well but in so doing they will tolerate schedule and cost/effort overruns. Sophisticated testing coverage metrics have not yet been introduced as the group produces very few defects and have not needed to fix the testing process.

The prescription for such a group is to focus on enhancing their estimation model. With stable requirements and a group well trained in process, estimation should improve. In addition, the group will probably want to focus on finding efficiencies in testing coverage, as they may be duplicating testing and wasting effort.

The third sample map shows a project that has had to deal with substantially more requirements change than usual. In most other respects, the project appears to do a good job. However, the relatively low process compliance figure might raise some question about the reliability of the data. The prescription for this group is to focus on process compliance and process improvement. If the low process compliance has not influenced the quality of the metrics, then the local process group should look to this project for best practices and ways to change the process to make it easier to handle a rapidly changing market. This project should generate change requests to their process to allow it to more easily handle requirements change.

These sample maps show a way of displaying a lot of data about a process in one chart in order to raise issues. The goal is to use measurement as a diagnostic tool to target process improvement efforts. Depending on the business drivers, a business may seek to maximize different aspects of the basic metrics collected.

This is, of course, a long way from the type of measurement we are likely to see in twenty years. This is very much a work in progress and will improve with use. Using a number of

metrics as a map to diagnose development groups will likely become more common. In addition, such an approach can be configured to local business drivers and does not require the imitation of models successful in other business environments. Diagnostic maps for innovation can be constructed.

Such diagnostic maps are simply one example of the way the measurement of economic processes will tend more toward biology in order to measure the living force and movement that makes a business succeed.

Conclusion

What does this narrative have to do with software measurement? Why present a paper like this to a conference on software managers and technical specialists on software development?

First, software measurement specialists are part of a long tradition of economic theorists, even if many don't recognize their ancestors. Notions of efficiency and how to model economic change are implicit in measurement strategies pursued. This paper argues that the efforts of professionals at a software measurement conference like this are struggling with measurement issues that have been known for decades. In addition, changes in the wider economy even in the past decade will produce new demands on software measurement professionals. Software process models based on producing for a protected government market dominated by security concerns require update for a competitive market economy. By setting the context for current issues and stressing the consistency of change, software managers can find constructive ways to respond to the changes with new ways of modeling data and assessing metrics.

Second, software measurement will be difficult because it requires a sophisticated understanding of how innovation can be fostered. Economic theorists have know for a long period of time that the short-run models do not capture the innovation that drives growth. Furthermore, the aggregated statistics and national income categories useful for state planning have also been shown to lack coherence over the long run. This should encourage skepticism about the utility of producing development metrics such as lines of code across many development groups and languages in a rapidly changing environment.

Finally, as a professional now involved in a software development metrics program, I am interested in making software measurement work for business benefit. I have absolute confidence that in the next twenty years successful new measurement strategies for software will be a common feature in all successful businesses. To my mind, measurement must seek to take account of innovation and look for ways to map what is essentially a living process. In order for such maps to work, data accuracy, data definition, and automated collection of data that emerges naturally from software development will be essential for success.

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[1] For the best summary in the shift of population growth, see C.M. Cipolla, *The Economic History of World Population*, 6th ed., (Harmondsworth, 1974).

2 See especially W.W. Rostow, *Theorists of Economic Growth from David Hume to the Present* (New York: Oxford University Press, 1992). Based on rigorous use of primary sources and personal experience in government, this work by the prominent development economist reviews major economic thinkers in terms of their views on economic growth.

[3] See Joseph Schumpeter, *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process* (New York: McGraw-Hill, 1939).

[4] The tendency of modern capitalist growth to show long-run cycles around a dynamic equilibrium of the relative prices between raw materials and manufactured good was outlined by N.D. Kondratieff, who did not manage to escape Stalin's Gulags for his heresy. See N.D. Kondratieff, "The Long Waves in Economic Life," *Review of Economic Statistics*, 17, No. 6 (November 1935), pp. 105-114. Much of my definition of waves outlined here come from the influence of W.W. Rostow and my seminars and discussions with him in the early 1990s. For his views in the 1970s, see *The World Economy: History and Prospect* (Austin: University of Texas Press, 1978).

[5] Economic historians occupy strange intellectual turf, between practicing economists and historians. For a good exploration of this creative tension, see C.M. Cipolla, *Between Economics and History: An Introduction to Economic History* (Oxford: Basil Blackwell Press, 1991).

[6] As always, I suggest reading the key primary sources for these individuals. Absent that detail, Rostow, *Theorists of Economic Growth* provides liberal quotations from primary sources.

[7] For example, Alfred Marshall gave testimony in 1887 before the Gold and Silver Commission of the British government to discuss the impact of currency on unemployment. This testimony remained his major published statement on currency for decades.

[8] Alfred Marshall, *Principles of Economics*, 8th ed. (London: Macmillan, 1930), pp. xv.

[9] See J.M. Keynes, "Alfred Marshall, 1842-1924," in A.C.Pigou (ed.), *Memorials of Alfred Marshall* (London: Macmillan, 1925).

[10] This section is drawn from the excellent work of Michael A. Bernstein, *The Great Depression: Delayed Recovery and Economic Change in America, 1929-1939* (Cambridge: Cambridge University Press, 1987). My conclusions are an interpretation of Bernstein's data and his basic argument. Bernstein's work has been influential in the assessment of the utility of many New Deal economic measures. In particular, the Glass-Stegall restrictions on banking only repealed at the end of 1999 appear as policy measures not needed for a healthy economy allowing a healthy flow of investement.

[11] These themes are covered in my dissertation, "The Struggle with Democracy and United States Leadership in India, British West Africa, and Argentina: The Eisenhower Administration in Pursuit of Internationalism." Ph.D. Dissertation, 1997, University of Texas at Austin.

[12] On the response to the Soviet economic and technical challenge, see Robert A. Divine, *The Sputnik Challenge: Eisenhower's Response to the Soviet Satellite* (New York: Oxford University Press, 1993).

[13] Many economists had recognized the importance of markets previous to this, but their arguments gained currency with the events in the 1970. For example, F.A. Hayek argued against socialism as a "Fatal Conceit" for the notion that humans through government could construct mechanisms to rival a market. Such a view became widely accepted in many quarters in the 1980s. See F.A. Hayek (b. Caldwell ed.), *Contra Keynes and Cambridge: Essays, Correspondence* (Chicago: University of Chicago Press, 1995) for early work. See *The Fatal Conceit* (Chicago, University of Chicago Press, 1991) for a later statement.

[14] The best example of this is the excellent work by Walter Wriston, *The Twilight of Sovereignty: How the Information Revolution is Transforming Our World* (New York : Scribner, 1992). Wriston is a good example of the economic theorist active in business producing superior work to that found in academics. See especially his section on the inability of GDP to measure intellectual products.

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