The Employment Effects of Advances in Internet and Wireless Technology: Evaluating the Transitions from 2G to 3G and from 3G to 4G

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EXECUTIVE SUMMARY

Continuing investments to upgrade the wireless broadband Internet infrastructure, including the transitions from 2G to 3G wireless technologies, and now from 3G to 4G, had produced cascades of innovation. Based on previous advances, the current transition to 4G technologies is likely to spur significant new job creation and growth which could help the American economy restore gains in incomes and business investment. New econometric analysis set forth in this study shows that the investments and innovation entailed in the transition from 2G to 3G wireless technologies and Internet infrastructure spurred the creation of some 1,585,000 new jobs from April 2007 to June 2011. The investments being undertaken today to upgrade wireless network and Internet technologies from 3G to 4G hold comparable promise for job creation. This analysis estimates that under the current transition, every 10 percent increase in the adoption of 3G and 4G wireless technologies could add more than 231,000 new jobs to the U.S. economy in less than a year. Based on the substantial economic benefits arising from advances in wireless broadband infrastructure and the adoption of devices that take advantage of that infrastructure, national policy should actively promote the rapid deployment and broad adoption of 4G wireless broadband.

Wireless Advances Created Jobs Even in Recession

Applying a unique database that provides detailed information on the ownership of mobile devices that operate on successive generations of wireless infrastructure, to state-by-state employment data, the authors of the study show:

- The adoption of cell phones and other mobile devices supported by a shift from 2G to 3G Internet and wireless network technologies led to the creation of nearly 1.6 million new jobs across the United States, between April 2007 and June 2011 – even as total private sector employment fell by nearly 5.3 million positions.

- The rapid transition from 3G to 4G mobile broadband networks should continue to stimulate new job creation in a short time frame, generating more than 231,000 jobs for every 10 percentage point gain in penetration rates within a year.

The research found that a 10 percentage point gain in penetration of a new generation of wireless technology in a given quarter leads to a 0.07 percentage-point gain in employment in the following quarter and continuing gains in subsequent quarters. These results suggest that a national job creation strategy should include or encourage appropriate measures to accelerate the deployment of 4G infrastructure.

4G Can Help American Meet Its National Broadband Goals

In addition to jobs gains, which the authors verify with five additional statistical tests, widespread deployment of 4G technology could help the country achieve universal broadband service by ensuring that this service becomes quickly available to many rural Americans who currently lack high-speed connectivity. 4G-enabled mobile services also could provide a less costly way for lower- and moderate-income Americans to access broadband.

The advent of new generations of wireless technology will also enhance the overall benefits of Internet connectivity and related advances in information and communications technologies (ICT). The McKinsey Global Institute, for example, has estimated that the Internet contributed about three percent to global GDP in 2009 and was responsible for 21 percent of U.S. GDP gains over the last five years.

This study also documents how the transition from 2G to 3G enabled or promoted the development of new products, services and industries. It further examines how the current, ongoing shift to 4G wireless infrastructure may open the door to a wide range of additional applications, services, products and new industries. These developments should generate or promote economic gains at least comparable to those produced by the build-out and adoption of 3G technologies.

Investments in 4G mobile wireless technologies and infrastructure networks hold particular promise in areas such as online retail, health care, energy, and business services.

- Mobile e-commerce, for example, increased several-fold in recent years, growing from about $1.4 billion in 2009 to between $6 billion and $9 billion in 2011 according to ABI Research. The shift to 4G can be expected to accelerate this growth.

- Savings from the wide use of electronic medical records created and accessed wirelessly, along with other "mHealth" apps, could total some $15 billion a year using current wireless technologies, and those savings would also grow as 4G apps become widely available and used.

- A national Smart Grid that applied wireless technologies to the nation's electricity networks could save $20 billion annually by simply reducing power outages, according to the National Energy Technology Laboratory. A 4G-based Smart Grid would save an additional $10 billion by further reducing the incidence of power failures.

- Cloud-based services, which are gaining rapidly in popularity, also would benefit from enhanced 4G wireless. Juniper Research, for example, estimates that the market for mobile-based cloud services could reach $39 billion by 2016, assuming wide deployment of 4G infrastructure and devices.

Policymakers Should Encourage Private Sector Investment in 4G Wireless Technologies

The rapid deployment of 4G technologies and the innovations that will accompany them should generate significant and widespread societal gains, including a stronger economic recovery and expansion from the recent recession. Policies to promote the full deployment of 4G, therefore, should be part of any national job creation and economic strategy.

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I. Introduction

Innovations do not occur on a predictable schedule. Nevertheless, there is strong evidence that the overall pace of innovation in information and communications technologies has accelerated in recent decades. Equally important, the rate at which businesses and households adopt these new technologies also have accelerated, including the changes, large and small, that firms and households have accepted to make effective use of these new technologies. It took more than 40 years for a majority of American businesses and households to adopt electrification. Nearly a century later, the current generation of American business and families adopted personal computers in about half of that time. Similarly, mobile phone use, following a slow start, spread to a majority of U.S. households over a little more than a decade. The most recent innovations in this area have involved smart phones and upgrades in the Internet and wireless infrastructures on which smart phone applications depend. The shift from 2G to 3G infrastructure occurred in 10 years, with 3G in place in 2005. Smart phones came on the market in 2005; and industry analysts expect that half of American households will own the devices by the end of 2011.

The pace at which businesses and households adopt new technologies can have large economic consequences. Computers and the Internet are "general purpose" innovations which have been adapted successfully across every industry. By enhancing efficiency, promoting innovation and generating significant additional growth across industries, they have had large and far-reaching economic effects. Economists trace as much as three-fourths of productivity gains in the second half of the 1990s, for example, to the spread and effective use of information technologies. ICT (information and communication technology), including the Internet, has led directly to the creation of many thousands of new businesses, tens of thousands of new goods and services, and an untold number of new jobs.

This study explores the economic effects of an ICT innovation that has provided a platform for other innovations, the upgrading of the wireless infrastructure from 2G to 3G, the use of mobile devices that depend on 2G and 3G, and the potential impact of the current, on-going transition from 3G to 4G. With each new generation of wireless and web infrastructure, the speed and capacity of the Internet and mobile devices to transmit and receive data, voice and images have increased sharply. Moreover, these advances also have reduced the cost and price of these services. We will review a range of mobile-based commercial operations which followed from the transition from 2G to 3G, including mobile e-commerce, mobile social networking, and location-based services.

We also will analyze the job gains linked to the spreading use of mobile telephony as cell phone technologies advanced to take advantage of the increased capacity of 2G and 3G. By applying regression analysis to evidence of the ownership of cellular telephones drawn from the Nielsen, Q4'06-Q2'11 Mobile Insights survey, a sample that includes smart phones that operate on successive generations of wireless infrastructure -- 2G, 2.5G, and 3G – and state-by-state employment data, we find that the adoption and use of successive generations of cell phones from April 2007 to June 2011, supported by the transitions from 2G to 3G, led to the creation of more than 1,585,000 new jobs across the United States. Moreover, every 10 percentage point increase in the penetration rate of 3G and 4G phones and devices occurring as we write today -- in the last quarter of 2011 -- should add 231,690 jobs to the economy by the third quarter of 2012. We confirmed these results by testing them in five separate ways for their "robustness" or reliability, based on alternative technical specifications and data variations (see Appendix). These results are also remarkable, because they occurred while total private-sector employment was contracting by nearly 5.3 million jobs, from 114,438,000 to 109,170,000 positions. It is reasonable to conclude that the job gains associated with the adoption of new cellular phone technologies would have been substantially greater, if overall employment were also expanding.

Finally, we examine the types and dimensions of economic changes and benefits which may attend the current transition from 3G to 4G, including new goods, services, businesses and employment which may be enabled by the diffusion of a higher-capacity 4G wireless infrastructure and next generation cellular phones and other devices. Again, many of these expected benefits involve the application of ICT-based 4G services to a range of 4G mobile platforms, including smart phones. These applications include mobile-based emergency networks, mobile applications for a Smart Grid electricity network, mobile-enabled health care, and combinations of cloud computing and mobile devices.

We cannot calculate the precise extent or value of these benefits, since they have not occurred. However, we are confident that these technological benefits will likely prove to be substantial and at least comparable in scale to the benefits of the adoption of 3G. In some cases we offer rough estimates of the general dimensions of those benefits. Moreover, we also expect that the substantial job gains associated with the adoption of 3G mobile devices will continue with the adoption of 4G mobile devices. Whatever the final effects of 4G-based technologies, the record of economic benefits arising from advances in web and wireless infrastructure and mobile devices establish that national policy should promote the rapid and broad adoption of 4G.

II. Progress in Mobile Information and Communications Technologies

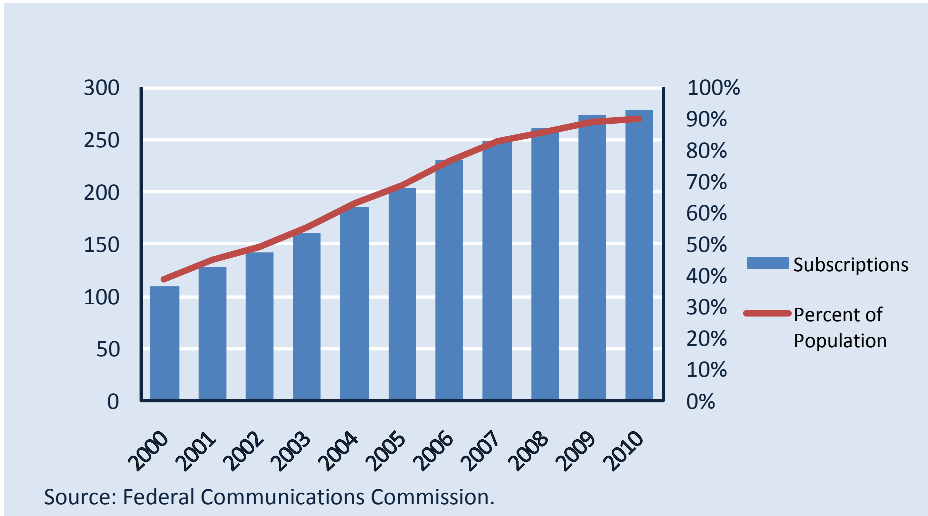
The mobile devices and platforms central to the economic and social usefulness of 3G and 4G have evolved as rapidly as the web infrastructure on which they depend. As mobile devices became smaller, lighter, more technologically advanced and more affordable, they moved from limited niche products for well-to-do business people to ubiquitous tools for communicating and accessing information used by hundreds of millions of people. The next generation of mobile phone and mobile device technologies that rely on 4G infrastructure almost certainly will also give rise to many new applications and uses by businesses and consumers. To better understand the potential economic benefits of 4G mobile technology, we begin by examining the expanding benefits derived from the use of mobile devices as the wireless and web infrastructure moved from 1G to 2G and from 2G to 3G.

Mobile providers rolled out the first generation of cellular wireless networks in the United States in the early-1980s, before the commercial emergence of the Internet. Until that time, mobile phones relied on tall, high-power transmitters and receivers which used a limited number of radio frequencies to cover entire cities. These conditions sharply limited the network capacity of these mobile phones. For example, the first mobile phone network for New York City could support a total of 700 mobile customers and no more than 12 conversations at any time. The introduction of 1G wireless infrastructure allowed mobile phone providers to sub-divide cities into "cells" or small geographic areas and use lower-power transmitters that expanded capacity by reusing radio frequencies. Providers also introduced other innovations as part of these first-generation mobile phone networks, including automatic circuit switching and handover from cell to cell, so that users could move across coverage areas without losing their connections. However, these 1G cell phones had limited utility. They were extremely heavy, cost as much as $4,500 (in 2011 dollars), and carried monthly charges averaging about $350. Further, their coverage was unreliable, and voice quality was poor. Nevertheless, more than three million Americans subscribed to the service by 1990.

Mobile telephony experienced major changes with the introduction of second generation (2G) web and wireless infrastructure and wireless systems, which came on line in the early 1990s. The most significant innovation was digital voice encoding which supplanted the 1G analog system that transmitted calls over individual radio frequency channels, like FM radio stations. The new digital networks encoded phone signals using the binary code of 1's and 0's, and used new "multiplexing" technology to transmit multiple phone calls on the same frequency channel. These advances enabled mobile phone providers to substantially expand their network capacities and upgrade voice quality. With digital encoding, the new 2G systems also could transmit data as well as voice. This new capacity led quickly to the introduction of smart phones and the development and use of mobile data services and applications for them, including fax and, most crucially, email and Short Messaging Services (SMS). 2G mobile phone service providers also introduced new security and privacy innovations, including digital encryption to protect users from eavesdropping and cell phone fraud. And by 1999, CNN launched the first 24-hour SMS-based mobile news service – the predecessor to today's news apps – featuring breaking news, market updates, sports scores, and weather forecasts. However, the appeal and usefulness of the 2G mobile phones remained limited by their small storage capacity, slow download speeds of no more than 120kbps, and small screens.

Third generation (3G) wireless networks were the first to be considered "broadband." These wireless networks were slow to take off outside Asia and were not widely available in the United States until 2005. 3G technologies allowed network providers to improve both voice capacity and data transmission rates, which quickly achieved a range of 500kbps to 2Mbps and up to 14Mbps. The faster transmission rates supported significant additional innovations for users of cell phones, including much more sophisticated web browsing, streaming video, gaming, and multimedia messaging service (MMS). These enhanced capacities were also closely associated with the rapid spread of cellular service, which now includes 90 percent of American households. (Figure 1, below)

Figure 1: Cellular Phone Subscriptions in the United States, 2000-2010



3G broadband capacity also created a platform for the next major innovation in mobile telephony, the development of a wide range of new applications for smart phones. The 3G phones had been brought to market before the development of popular, new applications; and for several years, industry analysts speculated that 3G technologies would create a new mobile experience with a variety of new applications, rather than a single "killer app." The rapid spread of the iPhone and its subsequent competitors shifted the focus of mobile technology developers from simply creating smaller, thinner and lighter devices to combining the broadband connectivity of those devices with new hardware features such as touch screens, more powerful processors, GPS receivers, high resolution cameras, and accelerometers. These combinations created a new platform for the development of new software services and advanced high-bandwidth applications for a growing variety of smart phones and new mobile Internet tablets.

III. Critical Innovations for the 3G Mobile Internet

The worldwide growth of mobile phone use represents one of the broadest diffusions of new technologies on record, with an estimated 3.9 billion subscribers in the third quarter of 2011 according to a recent analysis by Ericsson. Ericsson further found that worldwide mobile broadband subscriptions (as compared to subscribers) grew an estimated 60 percent over the 12 months ending in the third quarter of 2011, at which time they totaled nearly 900 million. They forecast that the total will reach more than 4.5 *billion* by 2016. Finally, about 30 percent of all new mobile phones sold in the third quarter of 2011were smart phones, up from 20 percent in 2010.

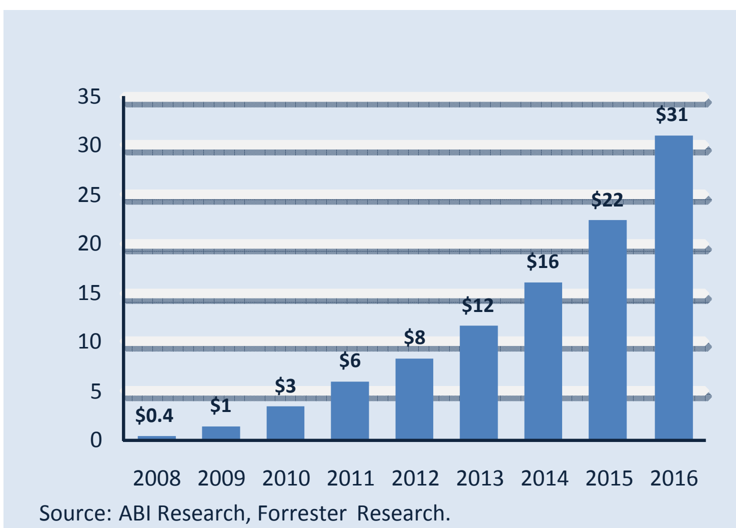
The combination of the enhanced capacities of the 3G wireless broadband platform and the new capabilities of smart phones and tablets have created a platform for the development of new software services and advanced high-bandwidth applications for new generation smart phones and mobile Internet tablets. Mobile access to online video and audio has provided the closest approximations to killer apps for 3G. Worldwide, online video and audio account for more than 35 percent of all application traffic on smart phones and 40 percent of app traffic for tablets. The only applications used more frequently are web browsers, which developed under 2G.

To gauge the impact of other new services and high-bandwidth applications that depend on the transition to 3G, we will focus on three categories of 3G-based services and applications: mobile e-commerce; mobile social networking; and location-based services.

Mobile E-Commerce

E-commerce has grown steadily as the Internet and wireless networks evolved from 1G to 2G and from 2G to 3G. Mobile e-commerce, however, required not only the diffusion of both 3G broadband and highly-enabled smart phones, but also the development of sophisticated retail applications for mobile platforms. As these elements fell into place, mobile shopping and related activities such as in-store search and comparison programs, coupon and daily deal services, and shopping applications such as bar code scanners have become much more common. A recent study from ABI Research, for example, estimates that mobile e-commerce sales in the United States, which accounted for sales of $1.4 billion in 2009, will increase by four-fold or more in 2011, to between $6 billion and $9 billion. Moreover, mobile e-commerce sales may be headed sharply higher in the near-future: The Internet marketing research firm comScore reports that 35 percent of the roughly 80 million smart phone subscribers in the United States, or 28 million people, already have made purchases on their cell phones. Further, a recent study by Google found that mobile shoppers spend on average of $300 per year on their smart phones, which based on the estimated 28 million people who make purchases using cell phones, suggests a total of $8.4 billion in mobile commerce sales this year, at the upper end of the ABI estimate.

Figure 2: Estimated U.S. Mobile E-Commerce Sales, 2008-2016



Mobile commerce sales are still modest compared to a projected $190 billion in U.S. online retail sales in 2011 and $4.5 trillion in all U.S. retail sales. Nevertheless, the recent, rapid growth in mobile e-commerce suggests that this segment will comprise a growing portion of the future retail market. Moreover, mobile e-commerce capacities may enhance other on-line retail and even in-person retail shopping. In particular, mobile commerce can undermine the local market power of traditional retailers, leading to lower prices and increased output. A recent *Wall Street Journal* story reported a Macy's marketing executive's view that, "mobile is going to be the end-all and be-all of how we are going to communicate with the customer." As more retailers invest in mobile web sites and applications, and more customers upgrade to smart phones with broadband connectivity, users may increasingly incorporate their mobile phones in their shopping.

This trend is already clear. Research shows that millions of U.S. consumers currently use 3G-enabled smart phones in conjunction with advanced applications and other software to shop. They search websites or the brick-and-mortar world for particular products and then compare product prices, reviews and performance, even when they intend to make their purchases on their PCs or at local stores. A recent analysis by Booz & Company, for example, estimated that between $155 billion and $230 billion in retail sales will be "influenced" by mobile applications, an upper range that exceeds total current online retail sales. This is a reasonable estimate, given other recent findings. A 2010 survey by Cisco found that 56 percent of American consumers are "calculating shoppers" who regularly use the Internet to search for products and pricing information. Further, research by Google found that between 15 percent and 30 percent of all Google search queries involving consumer products originate from mobile phones, including 15.5 percent of all searches for consumer electronics, 29.6 percent of searches for restaurants, and 16.8 percent of searches for automobiles. Google also reported that 53 percent of those using mobile search queries say that they have made purchases they associate with their mobile searches. These findings provide an alternate basis for estimating the indirect effect of advanced mobile phones on retail sales: $4.5 trillion in total U.S. retail sales, times 0.56 (the 56 percent of Americans who are "calculating shoppers"), times 0.15 (the 15 percent minimum of queries involving consumer products which originate from mobile devices) = $378 billion. If we also include the ambiguous figure of 53 percent (0.53), representing the percentage of people using mobile search queries who report they have made purchases associated with mobile searches, the total comes to $200.3 billion. This estimate falls well within the range of the Booz & Company projection of $155 billion to $230 billion in sales influenced or enabled by 3G infrastructure and technologies. It further suggests that the estimated $6 billion to $9 billion in direct mobile e-commerce retail sales this year are only a small part of the total impact of mobile devices and applications on retail sales.

The online auction site eBay, with more than 100 million active users and $9 billion in annual revenues, has been noted for offering an advanced and versatile mobile platform for online retail. The company has invested heavily to make its mobile apps a major access route for its customers. In response, consumers have downloaded eBay's 13 mobile apps – ten for iPhones and three for Android devices – more than 45 million times, and the company claims that eBay mobile records a new purchase every second. While eBay mobile applications have been available since 2003, mobile auction revenues began to rise sharply only with the adoption of 3G-enabled smart phones: Mobile sales on eBay auctions increased from $600 million in

2009 to nearly $2 billion in 2010; and the company estimates that its mobile sales may reach $4 billion in 2011. This rapid growth is linked to the recent, rapidly-expanding use of 3G enabled smart phones. The mobility and connectivity of these phones and the capacities of eBay's mobile apps enable its customers to monitor auctions on the go, 24 hours a day, over fast, secure Internet connections. Transactions that could bring together mobile buyers and sellers in real time were not possible before the transition from 2G to 3G and the development of broadband-enabled smart phones and applications. Imagine trying to browse eBay while keeping up with a competitive, multi-bidder auction with a phone that downloaded at 56 kB/s.

Mobile Social Networking

The shift from 2G to 3G also provided the platform for substantial innovations in the area of mobile social networking. This market has grown very rapidly in recent years, driven in large part by a series of new mobile services offered by social networking websites. The websites have been operating for nearly a decade, but only in recent years have their users been able to access them with mobile devices. Once Facebook, Google+, Twitter, Yelp and others recognized the appeal of mobile social networking, they focused investment and attention on their mobile sites. The result has been an extraordinary expansion of mobile social networking. In 2011, 56 percent of all U.S. smart phone users, or some 44 million people, used social networking mobile apps on a regular basis. Moreover, from 2010 to 2011, Facebook's mobile users jumped from about 100 million to more than 250 million; and the company's Chief Technology Officer has said that mobile would be Facebook's primary focus in 2011. Similarly, the young Google+ has some 25 million registered users, most of whom have downloaded the Google+ app on Apple and Android phones. The active, mobile user base of the micro-blogging service Twitter includes as many as 80 million of its more than 200 million registered users. The proof is in the tweets: From 2010 to 2011, the percentage of "tweets" coming from mobile devices increased from 25 percent to 40 percent, or about 80 million mobile tweets per-day. Finally, the mobile app users of the crowd-sourcing site Yelp, which features user-generated reviews of local businesses, increased from 2.5 million in 2010 to 4.5 million in 2011; and the company reports that 35 percent of all searches on the site come from mobile devices.

Table 1. Mobile Use of Social Networking Sites

Company	Valuation	Est. Revenues, 2011	Total Users	Mobile Users
Facebook	$70 billion	$4 billion	750 million active users, 60 million status updates per day	250 million mobile app users
Twitter	$8 billion	$200 million	200 million registered users, 200 million tweets per day	80 million mobile tweets per day
Yelp	$500 million	$85 million	53 million unique visitors per month	4.5 million mobile app users, 35 percent of all searches come from mobile devices

The data suggest that mobile devices currently account for roughly 30 percent to 40 percent of all social networking activity. As Facebook, Google+, Twitter, and Yelp together are expected to generate some $4.3 billion in revenues in 2011, $1.3 billion to $1.8 billion can reasonably be attributed to mobile users. And while the majority of social networking involves individuals in personal interactions, the boom in business-related social networks could, over time, increase productivity by enhancing the quality and quantity of employee interactions.

Location-Based Services

For several years, technology analysts have written about the commercial potential of providing services at the intersection of mobile, social networking, and real-time needs. Numerous entrepreneurs have invested in ventures focused on this "golden triangle" of services; and in January 2011, Forrester Research forecast that the "top mobile trend" for 2011 would be the "mobile/social/local combo." Many of the commercial opportunities associated with this combination depend on a user's geographic location, which has generated new interest in location-based services (LBS) that enable people to use mobile devices to interact in real time with merchants and friends in specific geographic areas. Like mobile social networking, these new services depend on the availability of 3G networks which allow anyone with a GPS-enabled smart phone to access high-bandwidth applications and services on-the-go.

Marketing by mobile broadband providers has promoted location-based services for several years, and the launch of location-based social networking businesses such as foursquare, Gowalla, Loopt, Google Latitude, Facebook Places and shopkick has increased their appeal. These services use smart phone apps that allow users to share their current locations with friends, and some offer coupons or loyalty rewards for visiting particular restaurants, bars, and other venues in the same general geographic area. LBS offer businesses new ways to connect with and draw potential customers based on their interests and geographic proximity, reward their loyal customers, and evaluate in a direct way the effectiveness of their advertising. From October 2010 to March 2011, the share of mobile users using LBS such as foursquare or Google Latitude increased from five percent to seven percent, a 40 percent jump in six months. By March 2011, nearly 17 million U.S. mobile subscribers, or 18 percent of all smart phone users, used LBS.

A recent study by the McKinsey Global Institute projects that by 2020, mobile location-based services will generate more than $80 billion in value, including $27 billion in revenues for mobile service providers and up to $57 billion in value derived by consumers, or "consumer surplus." The growth of LBS also should benefit advertisers by increasing opportunities for personalized, geo-targeted mobile advertising. Analysts from J.P. Morgan Chase estimate that U.S. mobile advertising revenues will reach $1.2 billion in 2011, twice the levels of 2010. Similarly, Gartner has forecast that the location-based mobile advertising market, worldwide, will reach $3.3 billion in 2011. Finally, the McKinsey Global Institute study estimated that by 2020, mobile advertising will generate up to $100 billion in new value for consumers.

IV. The Impact of New Cellular Technologies on Employment: A Technical Analysis

Economists and other researchers only recently have begun to analyze how improvements in Internet infrastructure and Internet-based mobile telephony use affect the economy. In 2010, a study by Arthur D. Little and Ericsson reported that, worldwide, a one-percent increase in broadband penetration was accompanied by a 1 percent increase in GDP. A more recent analysis by researchers at the Chalmers University of Technology found that every time a country's broadband speed doubles, the country's GDP rises 0.3 percent. These effects include jobs and investments related to creating equipment and other facilities for new infrastructure, productivity spillovers such as increased use of business services by construction or electronics firms providing new infrastructure, and new ways of conducting business based on increased broadband speeds. The mobile ecommerce, mobile networking and location-based services described above are examples of "induced" effects of a faster Internet and wireless infrastructure.

The Internet's economic benefits are manifest in output, productivity, standards of living, and employment. A recent study by the McKinsey Global Institute (MGI), for example, estimates that the Internet contributed about 3 percent to global GDP in 2009. By country, MGI estimates that the Internet accounted for 3.8 percent of U.S. output in 2009, a larger share than France (3.1 percent) and China (2.6 percent) but a smaller share than Japan (4 percent) and the United Kingdom (5.4 percent). MGI further calculated that in mature economies such as the United States, the Internet has accounted for 10 percent of GDP growth in the last 15 years and 21 percent of GDP growth over the last five years. Furthermore, a statistical analysis based on data from nine countries (United States, Japan, Germany, France, United Kingdom, Italy, Canada, South Korea, and Sweden) found that every 10 percent increase in Internet expenses was associated with gains in real per capita GDP of 1.2 percentage points. MGI further found that the maturity of a country's Internet ecosystem – based on usage, infrastructure quality, penetration, and expenditures on the Internet – correlates strongly with GDP *per capita* growth. The study estimates that for every one job destroyed by the Internet, 2.5 new jobs are created.

As the Internet has become increasingly integrated with mobile devices, improvements in cell phone technology supported by the generational upgrades in Internet and wireless infrastructure also have had a range of significant effects. Here, we will focus on the employment effects arising from changes in marketplace penetration of new cellular phone technologies. We focus on employment, because detailed employment data are available at the suitable level of geographic disaggregation for this analysis. This analysis relies on cell phone technology survey data from Nielsen, Q4'06-Q2'11 Mobile Insights Survey, employment data from the Bureau of Labor Statistics (BLS), and population data from the U.S. Census Bureau (Census). As we will see, we find that from the fourth quarter of 2006 to the second quarter of 2011, 1,585,302 additional jobs can be traced to the spread and increasing use of smart phones and other mobile Internet devices enabled by the transition from the 2G to 3G infrastructure.

The Nielsen surveys used here provide state-level data on the adoption of cell phone technologies, collected on a quarterly basis over the period from the fourth quarter of 2006 through the second quarter of 2011. Consumers were asked to identify the model of phone they use and their carrier. Using these survey results and weighting the responses for standard demographic variables, Nielsen calculates the penetration of each type of cellular technology available in the marketplace. Each technology is associated with a "generation" of cell phone development and web platform. All of the phones reported in the survey over this period used at least 2G technology and 2G wireless infrastructure. The phones, their technologies and associated generations are listed in Table 2, below.

Table 2: Cellular Telephony Technology by Generation

Technology	Generation
GSM	2G
TDMA	2G
CDMA	2G
iDEN	2G
EDGE	2.5G
CDMA 1x	2.5G
GPRS	other
UMTS	3G
CDMA EVDO	3G

Each cellular phone carrier followed a separate pathway of development. For example, a large part of AT&T's network initially was TDMA before the company shifted to GSM, both 2G technologies. The AT&T network then progressed to a 2.5G technology, EDGE. In addition, the application of GPRS boosted the capacities of both the GSM and EDGE phones. These technologies were superseded by the 3G UMTS technology. Typically, each phone has one technology corresponding to its generation of development, although a small number of phones have both TDMA and GSM. Nearly all devices also offer backwards compatibility within the same broad technology pathway, so a 3G phone will also include 2G and 2.5G technologies. All 3G phones for AT&T and T-Mobile also have GPRS technologies, but it is not certain that all 2.5G phones will. Technology pathways for each carrier are shown in Table 3, below.

Table 3: Technology Pathways by Carrier

	AT&T	Sprint (Sprint)	Sprint (Nextel)	T-Mobile	Verizon Wireless
2G	TDMA/GSM	CDMA	iDEN	GSM	CDMA
2.5G	EDGE	CDMA 1x	CDMA 1x	EDGE	CDMA 1x
3G	UMTS	CDMA EVDO	CDMA EVDO	UMTS	CDMA EVDO
other	GPRS			GPRS	

This analysis measures the relationship between the penetration of new cellular technologies and changes in employment. We built this analysis in four steps. First, we constructed a proxy for the number of cell phones for each generation of technology by summing the weighted counts of the associated technologies. For 2G, therefore, we total the counts for GSM, TDMA, CDMA, and iDEN. Similarly, for 2.5G, we sum the counts for EDGE and CDMA 1x; and for 3G, we sum the counts for UMTS and CDMA EVDO. We also include a variable that contains GPRS, which accompanies either EDGE or GSM but never stands on its own. These proxies may overestimate actual penetration rates for each generation, insofar as some phones carry more than one of each generation's technologies. However, those phones comprise a small portion of our total sample, so the proxy should be generally accurate.

Second, we estimate the percentage of penetration of 2.5G, GPRS and 3G technologies in the following way. Every cell phone in our sample has at least 2G technology, so we can represent the those percentages by dividing the number of phones with 2.5G technology by the number with 2G technology, the number with GPRS technology by the number with 2G technology, and the number with 3G technology by the number with 2G technology. These variables are independent of sample size and the growth of overall cell phone usage. Further, to obtain variables that represent the percentage changes in 2.5G, GPRS and 3G penetration rates by quarter, we distribute the values above over the calendar quarters. And since some cell phone users wait for extended periods before upgrading their phones, upgrades also can skip a generation(s).

Since our goal is to measures the employment effects in state economies of large increases in the use of new cell technologies, we also construct a variable that represents the change in cumulative cell phone generational penetration, which we call ΔGenPen. This variable, which is the sum of the differenced variables, is a measure of the "newness" of cell phones in each quarter, by geographic location. For example, in a particular quarter, 2.5G penetration increases by 20 percentage points and 3G penetration increases by 10 percentage points. In this case, the ΔGenPen would equal 30. This variable can account for any additional impact coming from skipping a generation of cell phone technology, since everyone who has 3G technology also has 2.5G technology, and so on. This is appropriate, since if the adoption of these technologies has employment effects, an increase from 2G to 3G should have greater effects than an increase from 2.5G to 3G. Finally, our employment variable comes from BLS data and measures the log differences of seasonally-adjusted non-farm employment on a quarterly basis and at the state level. Our population variable comes from Census data and measures state population on an annual basis.

Summary Statistics and Technology Dispersion by State

Table 4, below, provides the summary statistics for all of these variables: population, employment, 2G penetration, 2.5G penetration, GPRS penetration, 3G penetration, and ΔGenPen. Each quarter has 50 observations, one for each state; and each variable has 950 observations, for 50 states over 19 quarters. We present the mean values for each variable, the standard deviation and minimum and maximum values, both the average for the entire period and for the first and last quarters surveyed (Q4-2006 and Q2-2011).

Table 4: Summary Statistics -- Entire Period, Beginning of Period, End of Period

Variable	Mean	Std. Deviation	Minimum	Maximum
		Population		
Average	6,096,434	6,701,265	512,841	7,300,000
4Q 2006	5,960,185	6,610,763	512,841	36,000,000
2Q 2011	6,162,876	6,848,235	563,626	37,300,000
		Employment		
Average	2,653,641	2,761,002	280,300	15,200,000
4Q 2006	2,720,124	2,861,475	283,600	15,100,000
2Q 2011	2,607,756	2,741,221	288,700	14,100,000
		2G Penetration		
Average	1.02	0.02	1.00	1.18
4Q 2006	1.00	0.00	1.00	1.01
2Q 2011	1.03	0.03	1.00	1.12
		2.5G Penetration		
Average	0.80	0.12	0.33	1.00
4Q 2006	0.63	0.14	0.33	0.99
2Q 2011	0.93	0.04	0.77	1.00
		GPRS Penetration		
Average	0.45	0.19	--	1.00
4Q 2006	0.42	0.18	0.01	0.86
2Q 2011	0.46	0.14	0.10	0.78
		3G Penetration		
Average	0.43	0.16	--	0.82
4Q 2006	0.17	0.09	--	0.62
2Q 2011	0.66	0.06	0.48	0.78
		ΔGenPen		
Average	**0.05**	**0.13**	**(1.08)**	**0.63**

Average state employment fell over the entire period, while population increased moderately. GPRS penetration changed little over the period, which corresponds to GPRS having already been widely adopted by AT&T and T-Mobile. However, 2.5G and 3G penetrations both rose sharply over this period. Increases in 3G penetration outpaced those for 2.5G, indicating that many users upgraded from 2.5G phones to 3G phones, an upgrade that would leave 2.5G penetration unchanged while increasing 3G penetration. ΔGenPen averaged +0.05 per quarter during the time period with a relatively large standard deviation of 0.13, which accounts for differences between both states and periods.

Table 5, below, details the dispersion of each technology, by state. The table shows the penetrations rates for each technology at the beginning and end of the 19-quarter period, for each state. The average value across the 19 quarters for the change in the penetration rates of generations of the technology, ΔGenPen, also is shown. West Virginia had the highest average

ΔGenPen, at 0.067, and Maine and South Dakota are tied for the lowest value at 0.028. There is a small correlation of 0.17 between average state population and average ΔGenPen, but there are no other obvious relationships. However, this result may be misleading, given that the duration of the study is brief, and significant technological dispersion had already occurred before the first quarter of our study. For example, states with the highest penetration rates for these technologies also tend to adopt those technology sooner, and consequently we might see higher averages for ΔGenPen in states that tend to use less technology overall.

Moreover, the data show that while there were large differences in 3G penetration by state at the beginning of the survey period, in the fourth quarter of 2006, those differences contracted sharply by the second quarter of 2011. In late 2006, 3G penetration by cell phone users ranged from less 7 percent or less in Kansas, Montana and Wyoming, to 25 percent or more in Alaska, Connecticut and South Dakota. By the second quarter of 2011, 45 of 50 states had 3G penetration rates of between 50 percent and 78.5 percent.

Table 5: ΔGenPen and Changes in 2G, 2.5G, GPRS, and 3G Penetration Rates, by State

State	ΔGenPen Average	2.5G			GPRS			3G		
		4Q-06	2Q-11	Change	4Q-06	2Q-11	Change	4Q-06	2Q-11	Change
AK	**0.029**	0.621	0.781	**0.160**	0.379	0.739	**0.360**	0.621	0.629	**0.008**
AL	**0.063**	0.418	0.893	**0.475**	0.581	0.606	**0.025**	0.097	0.730	**0.633**
AR	**0.057**	0.326	0.951	**0.624**	0.855	0.628	**-0.227**	0.083	0.705	**0.622**
AZ	**0.037**	0.664	0.939	**0.275**	0.433	0.394	**-0.038**	0.214	0.646	**0.432**
CA	**0.047**	0.620	0.921	**0.302**	0.515	0.545	**0.030**	0.200	0.716	**0.516**
CO	**0.042**	0.643	0.934	**0.291**	0.484	0.431	**-0.053**	0.196	0.706	**0.510**
CT	**0.038**	0.675	0.936	**0.261**	0.504	0.535	**0.031**	0.294	0.680	**0.386**
DE	**0.041**	0.615	0.955	**0.340**	0.333	0.318	**-0.015**	0.202	0.613	**0.411**
FL	**0.049**	0.520	0.892	**0.372**	0.521	0.531	**0.011**	0.152	0.649	**0.497**
GA	**0.049**	0.560	0.918	**0.357**	0.489	0.481	**-0.009**	0.142	0.683	**0.542**
HI	**0.054**	0.575	0.911	**0.336**	0.525	0.558	**0.033**	0.109	0.707	**0.598**
IA	**0.044**	0.723	0.979	**0.257**	0.216	0.288	**0.072**	0.102	0.557	**0.456**
ID	**0.051**	0.661	0.945	**0.284**	0.305	0.354	**0.049**	0.121	0.705	**0.584**
IL	**0.050**	0.556	0.913	**0.358**	0.474	0.514	**0.039**	0.162	0.667	**0.505**
IN	**0.047**	0.641	0.936	**0.295**	0.415	0.460	**0.045**	0.155	0.660	**0.506**
KS	**0.051**	0.616	0.930	**0.314**	0.486	0.467	**-0.019**	0.070	0.694	**0.624**
KY	**0.064**	0.416	0.920	**0.504**	0.600	0.669	**0.070**	0.106	0.678	**0.572**
LA	**0.063**	0.479	0.924	**0.445**	0.612	0.701	**0.089**	0.125	0.717	**0.592**
MA	**0.047**	0.606	0.912	**0.306**	0.404	0.450	**0.046**	0.156	0.657	**0.502**
MD	**0.048**	0.595	0.923	**0.328**	0.381	0.403	**0.021**	0.165	0.686	**0.521**
ME	**0.028**	0.512	0.950	**0.438**	0.698	0.466	**-0.232**	0.254	0.543	**0.289**
MI	**0.045**	0.603	0.915	**0.312**	0.330	0.351	**0.021**	0.149	0.627	**0.478**
MN	**0.042**	0.640	0.915	**0.275**	0.451	0.441	**-0.009**	0.137	0.627	**0.490**
MO	**0.050**	0.548	0.903	**0.355**	0.601	0.565	**-0.036**	0.098	0.673	**0.575**

MS	0.057	0.504	0.949	0.445	0.719	0.710	-0.008	0.086	0.670	0.583
MT	0.046	0.957	0.965	0.007	0.048	0.265	0.217	0.048	0.648	0.600
NC	0.046	0.651	0.928	0.277	0.351	0.370	0.019	0.140	0.670	0.530
ND	0.054	0.962	1.000	0.038	0.059	0.414	0.355	0.203	0.785	0.582
NE	0.038	0.745	0.938	0.193	0.204	0.250	0.046	0.178	0.624	0.445
NH	0.041	0.682	0.953	0.271	0.231	0.283	0.053	0.193	0.601	0.408
NJ	0.040	0.708	0.957	0.249	0.402	0.424	0.022	0.225	0.677	0.453
NM	0.038	0.744	0.947	0.203	0.352	0.322	-0.030	0.184	0.688	0.504
NV	0.047	0.622	0.929	0.307	0.484	0.512	0.028	0.219	0.729	0.510
NY	0.050	0.627	0.921	0.294	0.383	0.479	0.096	0.175	0.686	0.511
OH	0.041	0.694	0.940	0.247	0.324	0.324	-0.001	0.169	0.657	0.488
OK	0.059	0.451	0.913	0.462	0.830	0.779	-0.051	0.072	0.716	0.644
OR	0.043	0.643	0.923	0.280	0.522	0.519	-0.003	0.164	0.660	0.496
PA	0.052	0.616	0.927	0.311	0.370	0.460	0.090	0.146	0.675	0.529
RI	0.047	0.534	0.948	0.413	0.386	0.392	0.006	0.167	0.586	0.419
SC	0.045	0.702	0.939	0.237	0.330	0.413	0.083	0.198	0.683	0.486
SD	0.028	0.972	0.954	-0.019	0.087	0.242	0.155	0.300	0.676	0.376
TN	0.044	0.653	0.939	0.286	0.428	0.398	-0.030	0.157	0.700	0.542
TX	0.055	0.589	0.926	0.337	0.560	0.618	0.059	0.142	0.735	0.593
UT	0.046	0.657	0.914	0.257	0.475	0.532	0.057	0.172	0.681	0.509
VA	0.040	0.701	0.941	0.240	0.338	0.329	-0.009	0.173	0.662	0.489
VT	0.031	0.989	0.773	-0.217	0.011	0.407	0.396	0.094	0.481	0.387
WA	0.042	0.634	0.918	0.284	0.503	0.505	0.002	0.183	0.655	0.472
WI	0.037	0.589	0.938	0.349	0.543	0.375	-0.168	0.184	0.660	0.476
WV	0.067	0.356	0.913	0.557	0.509	0.581	0.072	0.172	0.747	0.575
WY	0.031	0.878	0.944	0.065	0.122	0.097	-0.025	0.000	0.520	0.520

Regression Methodology

The empirical challenge is to test and identify any causal effects from changes in cellular phone technology, measured by changes in cumulative generational penetration, on employment by state. For example, we have to isolate or exclude potential feedback or opposite effects. For example, increased local employment will boost spending power and thereby may cause users to upgrade their cell phones, in contrast to increased adoption of new generations of cell phones that increases productivity and output, and therefore employment.

To isolate the causal effect of ΔGenPen on employment, we use the Granger causality test, a widely-employed statistical method developed by Nobel Laureate Clive Granger. Granger's key insight in developing this method, stated in technical terms, is that recursive substitution of a dynamic system can reduce it to a bivariate system: You can test the potential causal relationship between two related variables so long as you include many lags of the dependent variable in the regression. Using this method, a time series *X* can be said to Granger-cause a time series *Y,* if the lagged values of *X* provide statistically significant information about future values of *Y* in a regression that also includes lagged values of *Y* as independent variables.

Specifically, we can estimate the following linear regression to test whether increases in the penetration rates of more advanced cell phone technologies cause changes in employment:

$$(1)\quad \Delta(\log(\text{Employment}_{it})) = \beta_1 \bullet \Delta(\log(\text{Employment}_{i(t\text{-}1)})) + \beta_2 \bullet \Delta(\log(\text{Employment}_{i(t\text{-}2)})) + \beta_3 \bullet \Delta(\log(\text{Employment}_{i(t\text{-}3)})) + \beta_4 \bullet \Delta(\text{GenPen}_{i(t\text{-}1)}) + \beta_5 \bullet \Delta(\text{GenPen}_{i(t\text{-}2)}) + \beta_6 \bullet \Delta(\text{GenPen}_{i(t\text{-}3)}) + \eta_i + \gamma_t + \varepsilon_{it}$$

In this Granger causality test, our dependent variable is $\Delta(\log(\text{Employment}_{it}))$, the log differences of employment for state *i* at time *t*. The independent variables are three lagged values of the log differences in employment, and three lagged values of $\Delta(\text{GenPen}_{i(t\text{-}1/3)})$, or the cumulative generational penetration of cell phone technologies. State-specific fixed effects are captured by η_i, with a total of 49 dummy variables for the other states, and time-specific fixed effects are captured by γ_t, with a total of 18 dummy variables for the other quarters. This design takes account of the possibility that something unobserved about a given state leads it to both grow fast and adopt new technologies. The regression is weighted for state population, so the results can be applied to make national predictions and account for the Nielsen survey's small sample sizes in low population states.

Results

Table 6, below, reports the results of our Granger causality analysis. Column (1) includes state and time fixed effects, and column (2) removes state fixed effects. Given that employment is strongly cyclical, the time fixed effects should not be removed. Therefore, Column 1 shows that if employment falls in one quarter, it will tend to fall in the following quarter or, in technical terms, lagged changes in employment have positive coefficients and are statistically significant in explaining the current period changes in employment.

More important, the regression finds that the lagged values of changes in cumulative penetration of generational changes in cell phones help explain changes in employment in the current period, with a high degree of statistical significance. This suggests a causal relationship (Granger causality) between increases in the penetration of new generation cell phones and increases in employment. In fact, these results indicate that a one-percentage point increase in cumulative generational penetration of new technology cell phones causes a 0.007 percentage point increase in employment growth for the following quarter, a 0.00581 percentage point increase in employment growth in the second following quarter, and a 0.00483 percentage point increase in employment growth in the third following quarter. Stated differently, every 10 percentage point increase in the penetration of a new generation of cell phones in quarter-1 causes a 0.07 percentage point increase in employment growth in quarter-2, a nearly 0.06 percentage point increase in quarter-3, and nearly a 0.05 percentage point increase in quarter-4.

Table 6: Regression Results with State and Time Fixed Effects

Variable	Δ (log (Employment)) (1)	Δ (Log(Employment)) (2)
$\Delta(\log(\text{Employment}_{i(t\text{-}1)}))$	0.165***	0.249***
	(0.0519)	(0.0473)

Δ(log(Employment$_{i(t-3)}$))	0.196***	0.304***
	(0.0400)	(0.0335)
Δ(log(Employment$_{i(t-3)}$))	0.00729	0.120***
	(0.0418)	(0.0402)
Δ(GenPen$_{i(t-1)}$)	0.00700***	0.00612***
	(0.00225)	(0.00224)
Δ(GenPen$_{i(t-2)}$)	0.00581*	0.00460
	(0.00292)	(0.00275)
Δ(GenPen$_{i(t-3)}$)	0.00483*	0.00408*
	(0.00250)	(0.00222)
Constant	-0.00217***	-0.00124
	(0.000688)	(0.000751)

State Fixed Effects	Yes	No
Time Fixed Effects	Yes	Yes
Observations	750	750
R-Squared	0.854	0.840
Robust Standard Errors in parenthesis		
*** p < 0.01; ** p< 0.56; * p < 0.1		

This allows us to estimate the number of new jobs associated with generational shifts in cell phone technology. At the end of the third quarter of 2011, U.S. employment stood at 131,334,000. Therefore, each 10 percentage point increase in the adoption of new generation cell phones in that quarter would be expected to add 231,690 jobs to the American economy by the 3rd quarter of 2012.

Furthermore, we can isolate the job gains associated with the adoption or penetration of new generation cell phones over our sample period from the second quarter of 2006 to the second quarter of 2011. We can do this by using only the coefficients for the change in the generational penetration variable, β_4 through β_6, during the previous three quarters to predict the jobs growth (log differences) in each quarter, from the second quarter of 2007 through the second quarter of 2011. This analysis shows that over this period and across all states, the actual adoption or penetration of new generation cell phones contributed 1,585,302 jobs to the U.S. economy.

In the appendix to this study, we provide five tests of the robustness of these results. The five tests show that our results are highly reliable, suggesting that the economic benefits associated with the adoption of new technologies, which we discussed in previous sections, are very significant.

V. The Potential Benefits of 4G

We cannot know what innovative products and services will appear based on the additional capacities of a 4G wireless and web infrastructure, but analysts have identified certain areas in which 4G would provide a workable platform for new mobile products and services, based on its greater overall speed, reduced latency (the time it takes for s signal to travel between points within the network), and greater bandwidth carrying capacity, per MHz of spectrum. The advances associated with 4G should not only provide new capabilities, but also lower the cost of using wireless networks in both new and more "traditional" areas of mobile service. Areas in which 4G products and services could produce large public as well as private benefits include public safety management of crisis situations such as natural disasters, health care delivery, and the distribution and use of energy. It is also likely that the general relationship between job creation and rising penetration rates of 2.5G and 3G mobile devices will apply as 4G mobile devices are developed to take advantage of 4G wireless infrastructure.

Crisis Management

In 2010, natural disasters around the world killed nearly 260,000 people and caused an estimated $130 billion in economic damages. Responding to and managing these crises often involves the timely exchange and analysis of large amounts of location-specific video, audio and text information across a network of recipients, a task that would seem to be well-suited for 4G. Limited versions of these capacities have been developed for 3G. For example, in 2008, software programmers developed a crowd-sourcing mapping tool called "Ushahidi" to map and track incidents of violence in Kenya following the 2007 presidential election. The software allows witnesses of violence, as well as natural disasters and other crises, to submit geo-located text messages and tweets, which can be mapped geographically to help guide emergency response teams, NGOs, and other concerned parties. The Ushahidi software, which means "testimony" in Swahili, also has been used to coordinate emergency responses to the recent earthquakes in Haiti and Japan, the flooding in Queensland, Australia, the snowstorms in Washington, D.C., the large oil spill in the Gulf of Mexico, the armed conflict in Libya and, most recently, the riots in London. According to the *New York Times,* Ushahidi has become as ubiquitous in disasters as the Red Cross.

Japanese citizens responding to the March 2011 earthquake and tsunami made typical use of the Ushahidi platform. Within hours, they launched a Ushahidi-based website that allowed users to report the locations of trapped or injured earthquake victims. While email, cell phones and other normal means of communication were disrupted, text messaging continued to operate. Ushahidi received more than 9,000 geo-located reports which helped relief workers respond quickly. This effort may have been particularly effective, because Japan has more than 109 million mobile phone subscribers, 95 percent of whom subscribe to 3G service. Using a 4G platform, a next-generation Ushahidi would be able to integrate user-reported data in real time with police and other first-responder systems, including aerial surveillance, building schematics, and teams on the ground.

With this potential in mind, President Obama's FY 2011 budget included a proposal to help fund the development and deployment of a nationwide wireless broadband network dedicated to public safety. The funds would create a wireless communications network for emergency service agencies across the United States, including police, firefighters and emergency medical service personnel, to help them prevent or respond more efficiently and effectively to incidents endangering people or property.

The network's main purpose would be to support the daily operations of police, fire fighters and other public safety agencies. For example, the network could provide real-time video surveillance of critical areas, crime and fire scenes through mobile systems so police and firefighters can monitor and deploy the appropriate personnel, minute to minute. The system also would include wireless data and communication networks for officers in the field to consult databases, building plans and schematics, and public and private surveillance systems. First-responders on their way to fires, hostage situations, and other incidents could review real-time video from incident scenes and consult public and private databases, to help plan and coordinate their responses. Since 4G also should provide cost savings compared to a 3G platform and devices, the creation of such a network may be possible within current budgetary constraints. Moreover, the President's proposal also would provide access to the network to other public agencies, and it would encourage police and firefighting agencies to partner with appropriate commercial operators, so that each side might leverage the experience and assets of the other.

This 4G-based network could be especially valuable when major terrorism or natural disasters strike. The original impetus came from the 9/11 Commission's criticism of the lack of inter-operable communications systems among the diverse first-responders at the World Trade Center, and the resulting vulnerabilities for homeland security. The benefits from more routine use of the system also would be considerable. To begin, the initial proposed funding of $10.7 billion would create nearly 100,000 new jobs for network planners, laborers to lay and install cable, and technicians to build and install network devices, wireless access points, video surveillance cameras, gunshot detectors, and environmental sensors. As the network is established, it would create more jobs for network administrators and managers, technical support staff, network analysts, project managers, and IT analysts.

A wireless 4G network for public safety agencies also would produce direct savings for law enforcement and other emergency personnel, and large indirect savings from lives saved and property preserved. We cannot know how great those savings would be. However, if the new network and its technologies increase the productivity of police and fire agencies by just one percentage point per-year – less than comparable innovations have increased private-sector productivity – the direct efficiency savings would be nearly $2 billion per-year. Economic analysts at the Phoenix Center have further estimates that the indirect benefits from a full-fledged public safety network could come to another $2 billion to $6 billion per-year. Moreover, 4G private-sector networks using wireless devices – for example, spanning the global operations of multinational companies or, as we will see, providing widespread cloud-based access to applications and other software – will almost certainly provide the same types of benefits while public-provided 4G networks are still being developed.

Healthcare

Mobile health or "mHealth" also holds particular promise for a 4G network that would allow medical care professionals to use mobile devices to diagnose, treat and communicate with patients. The venture capital firm Kleiner Perkins Caufield & Byers, for example, has identified mobile health as one of eight key trends to watch. The benefits of mHealth should include greater patient access, improved treatment, and lower costs. The development of mHealth services would depend on 4G infrastructure, since it would entail physicians and other medical staff monitoring very large volumes of data, accessing electronic medical records (EMRs), downloading images and video for evaluation, and interacting with patients from remote positions in real-time.

Industry analysts expect that advanced mobile health technologies and smart-phone-based mobile applications could improve health care in many ways. Doctors should be able to reach more patients, including those in isolated areas, monitor them more closely, and intervene more rapidly. As mobile technologies continue to advance, patients may gain access to quality treatment from their homes, reducing costly office visits and hospitalizations which currently account for more than half of all health care expenditures. Health care mobile apps also may allow people to monitor much of their own health and better manage their prescription medications. Finally, 4G-based mobile health care will help address the problem which physicians claim is the biggest single obstacle to better care, accessing patient information when and where it is needed.

At last count, 81 percent of physicians carried smart phones. Moreover, recent surveys have found significant demand by both doctors and patients for mobile health technologies. Three-quarters of physicians say they would like and use mobile access to electronic medical records, to inform their prescription-related decisions and help them monitor their patients' health indicators. Further, half of all consumers say they would buy mobile technologies for health care, and 40 percent would pay for a monthly service that would send information directly to their doctors. This demand for mobile-based health care services, combined with the ubiquitous access by doctors to mobile devices using advanced operating systems and 3G+ networks, has already provided a platform for software developers to create more advanced applications for a 4G infrastructure.

Industry analysts and other experts predict that one of the first and most important applications of mHealth using 4G mobile networks will be more advanced apps for remote medical monitoring. These applications would include the real-time monitoring of intensive care patients by various specialists, ECG monitoring by cardiologists, and fetal monitoring by obstetricians. Other 4G-based remote applications may include more accurate diagnostic apps which, for example, could enable radiologists to remotely access CT scans or MRIs while on the go, and apps for real-time virtual consultation. Patients also should be able to use 4G-based mHealth applications, including apps that use cloud-based services, to monitor their own diabetes, asthma, obesity and other conditions.

A number of existing medical mobile apps can help illustrate the potential benefits of 4G-based health care. In February 2011, the Food and Drug Administration (FDA) approved a remote diagnostic imaging app for iPhones and iPads called "Mobile MIM," which allows radiologists to access CT, MRI, PET and SPECT scans remotely through encrypted transfers. Mobile MIM also enables physicians to zoom in, fuse and blend multiple scans, and measure distances, all with sufficient clarity and precision to support remote diagnoses. The FDA also has cleared the mobile app "AirStrip OB," which allows obstetricians to use their mobile devices to directly monitor the contraction patterns, fetal heartbeat, and blood oxygen levels of expectant mothers, review nursing notes on their patients' cervical dilations, vital signs and order results, all through compressed and encrypted data streams. The use of this app should not only save time; it also may help save lives when, for example, an emergency C-section is required based on the data and charts accessed through the app. The developer of this app, AirStrip Technologies, has launched two other remote monitoring apps, AirStrip Cardiology and AirStrip Patient Monitoring, which provide mobile access to real-time EKG data and a range of vital signs.

Based on surveys and studies of doctors and nurses, researchers estimate that the use of mobile apps should save doctors and nurses an average of 20 minutes, per-person, per-day while in the hospital and 15-to-20 minutes per-person, per-diagnosis outside the hospital. Based on these findings, the broad use of current apps would save some $15 billion per-year; and the savings and other benefits from broad use of more advanced, 4G-based mobile medical apps would be greater. One recent study estimated that the broad use of remote patient monitoring alone could save U.S. healthcare $197 billion over 25 years, or an average of $7.9 billion per-year. Other research has produced similar estimates. Moreover, these estimates do not include the value of mobile apps in saving lives, as illustrated, for example, by evidence of doctors using mobile phones to remotely diagnose and direct treatment for heart attack victims. In the future, some experts believe that the use of mobile apps such as AirStrip OB and others will help reduce America's infant mortality rate. If 4G-based applications could bring those rates in line with the average of all OECD countries, it would mean more than 8,000 American infant lives saved each year.

U.S. Energy Infrastructure

The 4G infrastructure also should provide a powerful platform for upgrades in the American energy infrastructure, including the development of an ICT-based "Smart Grid." The American Recovery and Reinvestment Act of 2009 provided $3.4 billion for first-stage investments in a Smart Grid that will deliver electricity to businesses and consumers using two-way digital data and communications systems, often linked directly to systems and appliances in offices, factories and homes. To create such an energy-grid network, the existing electrical grid is overlaid with a range of information and communications technologies, including extensive deployment of smart meters. This network would be so extensive and complex, that its effectiveness and efficiency will require the speed, latency and capacity of 4G wireless networks.

The creation of a nationwide Smart Grid will generate employment for thousands of people, including smart-meter manufacturing workers; engineering technicians, electricians and equipment installers, IT system designers and cyber security specialists, data entry clerks and database administrators, and business and power system analysts. The greatest economic benefits, however, would follow from the actual use of a Smart Grid. The Electric Power Research Institute (2010) has identified a number of ways in which a 4G-based Smart Grid could generate new economic benefits. Utility providers would be able to prevent "fault currents" from exceeding damaging levels by constantly monitoring the condition of the bulk power system and the capacity of each element to carry its load in real time. The network also would allow customers to use advanced metering systems to better manage their own power demand, in real time, based on adjusted pricing.

A Smart Grid also should reduce the incidence of power outages. If it succeeded in reducing such outages by 20 percent, as the National Energy Technology Laboratory predicts, that alone would save an estimated $20 billion per-year. And by virtually eliminating the damage from large-scale blackouts, a 4G-based Smart Grid could save the economy another $10 billion, per-blackout avoided. Other cost saving applications of a Smart Grid include automating the operations of the core grid, collecting the data required to reduce the cost and increase the effectiveness of maintenance programs, smart metering to shift power use by businesses and households from high-use times of the day and month to lower-use days and times, and the eventual development and operation of "smart buildings" that automatically optimize their electricity use.

Early versions of some of these applications have been available for several years, although their broad use will require a 4G platform. In 2005, for example, Oberlin College conducted a competition challenging its students to conserve and shift their electricity consumption. On average, dormitories cut their electricity use by 32 percent. However, two dormitories received real-time feedback on their energy use and costs through smart metering within a wireless data communication network. Students in the two networked dorms reduced their electricity consumption by 56 percent. A Smart Grid also could support homeowners and businesses that produce their own energy using small-scale generation from photovoltaics, solar thermal, and oil and natural gas generators. A Smart Grid wired into 4G wireless and web infrastructure could accommodate the use of such "microgeneration," provide additional energy when needed, and transfer excess energy from the microgenerators to other customers.

Cloud-Based Services, Universal Internet Access, and Other Potential, 4G-Based Benefits

There are a range of other possible applications of 4G mobile devices and wireless infrastructure that could help drive job creation and growth. In transportation, for example, plans for "real time traffic management" depend upon a network of 4G broadband and mobile devices. Under these plans, local transportation agencies will monitor traffic flows and message drivers on their mobile devices about backups and other traffic problems, to help reduce congestion which currently exacts large costs from the U.S. economy. In another area, 4G translation apps on mobile devices will facilitate business interactions, both in person and by phone, and possibly support public services and education for foreign-speaking nationals.

Larger potential economic benefits may emerge from the development and application of cloud-based services using 4G infrastructure and mobile devices. Several cloud-based mobile apps already have been introduced, including Dropbox, Apple's iCloud, and Gmail. Dropbox, for example, was valued at more than $5 billion in mid-2011. Industry analysts point to a range of innovations large benefits that could come from combining the cloud's remote access to applications, processing, and storage over the Internet with the constant connectivity of mobile devices. While 3G mobile apps have limited data storage, processing and power usage capacities, with cloud capacity, 4G mobile apps should be able to draw on the cloud's virtually unlimited storage and computing resources. This raises the prospect of much more powerful mobile apps that would require much less power from mobile phones and tablets. Cloud-based apps also would be able to store users' sensitive data on remote servers rather than on the mobile devices, enhancing the security of those data.

The mobile cloud also will enable users to use their 4G mobile devices to carry out tasks which are now carried out using wired cloud computing, such as accessing company databases, collaborating with colleagues on documents, and joining video conference calls. These apps also can be integrated with back-end customer relationship management software (CRM) such as SAP, Oracle, and Salesforce.com, so that sales staff, for example, can use their mobile devices to submit orders and perform other tasks away from the office.

Forrester Research has forecast that the global cloud computing market could reach $241 billion in 2020, a six-fold increase from an estimated $40.7 billion in 2011. As more firms integrate 4G smart phones and tablets in their business operations, a significant portion of these revenues will likely come from mobile business apps. In a recent survey conducted by Cisco, more than one-third of respondents cited "the need for constant connectivity" as their primary concern with adopting mobile cloud service, concluding that "to make the mobile cloud a reality, [service providers] should ensure the network infrastructure is robust and always available." In this regard, Juniper Research has forecast that the market for cloud-based mobile enterprise services will reach $39 billion by 2016. Such strong, rapid growth will not be possible without the connectivity provided by a 4G network and 4G mobile devices.

4G wireless networks also have the potential to expand access to broadband Internet and eventually achieve effective universal coverage. The Federal Communications Commission (FCC) reports that in mid-2010, 26.2 million Americans or 8.4 percent of the population lived in places not served by broadband. Moreover, the Census Bureau Current Population Survey (CPS) for February 2011 reported that some 100 million Americans or nearly 32 percent of U.S. households do not have broadband Internet service. While some households have no interest in broadband Internet, most who currently lack service say that the service is too expensive, they lack the necessary computer equipment, or they live in areas where service is unavailable. This "digital divide" is pronounced in rural areas, where more than 28 percent of households have no broadband service, and even more so among lower-income Americans. The CPS reported in February 2011 that only half of households with annual income of less than $35,000 subscribe to broadband service. Such low coverage among low and moderate-income households is a major reason why only 68 percent of the U.S. population has broadband service, compared to 96 percent of Koreans, 87 percent of Icelanders, and more than 70 percent of the residents of at least nine other countries.

The large numbers of Americans who still lack broadband service entails significant economic costs. A recent study by the World Bank found that among high-income countries such as the United States, every 10 percentage-point increase in broadband penetration is associated with an additional 1.21 percentage-points of economic growth. This suggests that merely connecting the 8.4 percent of the Americans living in places where broadband is currently unavailable would increase U.S. GDP by $148 billion per-year.

The Recovery and Reinvestment Act of 2009 directed the FCC to develop a national broadband plan to ensure that all Americans have affordable access to broadband service. The FCC plan published in March 2010 recognized the role that wireless broadband can play to help achieve true universal service. To begin, 99.6 percent of Americans live in areas with access to cellular service, 98.5 percent have access to 3G, and 90 percent subscribe to a mobile phone service. As cellular phone carriers roll out their 4G networks, it should cover many of the rural Americans who still lack broadband access and provide a less expensive means for lower and moderate-income Americans to secure that access.

VI. Conclusion

In this study, we have traced and analyzed the channels through which advances in wireless infrastructure and the development and adoption of new cellular technologies have promoted economic growth and employment. We also have constructed a novel database to test the impact of new cellular technologies on employment, and we find significant evidence that states which in a given period had adopted these technologies at higher-than-average rates for our sample experienced faster employment growth in subsequent periods. Our results strongly suggest that the adoption and use of successive new generations of mobile devices from April 2007 to June 2011, supported by the transitions from 2G to 3G wireless and web infrastructure, led to the creation of more than 1,585,000 new jobs across the United States. Based on this analysis and results, we conclude that a national strategy to promote stronger job creation should actively encourage or include measures to accelerate the adoption of 4G infrastructure.

Appendix

Testing the Robustness of the Employment Effects

Robustness Test 1 – Clustered and Unclustered Standard Errors

As the first check for the robustness of our results, we compare the cluster and unclustered standard errors (Table A-1, below). Our main regression specification is shown in column (1) with clustered standard errors. In Column (2), the standard errors are not clustered, and the coefficients on the second and third lags of ΔGenPen are more significant at the 5 percent level than in our main specification. However, the standard error on the first lag of ΔGenPen is actually larger with the unclustered estimate than with the clustered estimate, which implies slightly negative intracluster correlations.

Table A-1: Test of Robustness -- Clustered and Unclustered Standard Errors

Variables	Δ (log (Employment)) (1)	Δ (Log(Employment)) (2)
Δ(log(Employment$_{i(t-1)}$))	0.165***	0.165***
	(0.0519)	(0.0536)
Δ(log(Employment$_{i(t-3)}$))	0.196***	0.196***
	(0.0400)	(0.0471)
Δ(log(Employment$_{i(t-3)}$))	0.00729	0.00729
	(0.0418)	(0.0439)
Δ(GenPen$_{i(t-1)}$)	0.00700***	0.00700***
	(0.00225)	(0.00230)
Δ(GenPen$_{i(t-2)}$)	0.00581*	0.00581**
	(0.00292)	(0.00235)
Δ(GenPen$_{i(t-3)}$)	0.00483*	0.00483**
	(0.00250)	(0.00220)
Constant	-0.00217***	-0.00217**
	(0.000688)	(0.000901)

Cluster Robust	**Yes**	**No**
Observations	750	750
R-squared	0.854	0.854
Robust Standard Errors in parenthesis		
*** p < 0.01; ** p< 0.56; * p < 0.1		

Robustness Test 2 – Re-specifying the Universe of Cell Phone Users by Generation

Our second robustness check focuses on the construction of our universe variable, the denominator in calculating the penetration of each new generation technology. (Table A-2, below) Again, column (1) contains our main regression specification, where the number of 2G technologies reported is used as a proxy for the overall number of cellular phones. Column (2) calculates the number of cell phones according to the number of respondents to the survey. This could be considered a more accurate basis for calculating the universe of cell phones, since some 2G technologies are double counted when, for example, a phone has both GSM and CDMA capabilities. However, many phones capable of both GSM and CDMA are "world phones" and likely have other levels of technology that are also double counted, such as dual EDGE and CDMA 1x, and dual UMTS and CDMA EVDO. Since these world phones will cause double counting in the numerator of our variables of penetration or adoption, it is reasonable to allow the matching double-counting to occur in the denominator. The results of this second specification show coefficients on the lags of ΔGenPen in column (2) that generally are less significant and smaller than in column (1). However, the three coefficients are still jointly significant at the 10 percent level, implying that Granger causality holds in this alternate specification as well.

Table A-2: Test of Robustness – Alternate Terms for the Universe of Cell Phone Users

Variables	Δ (log (Employment)) (1)	Δ (Log(Employment)) (2)
Δ(log(Employment$_{i(t-1)}$))	0.165***	0.166***
	(0.0519)	(0.0525)
Δ(log(Employment$_{i(t-3)}$))	0.196***	0.197***
	(0.0400)	(0.0405)
Δ(log(Employment$_{i(t-3)}$))	0.00729	0.00674
	(0.0418)	(0.0418)
Δ(GenPen$_{i(t-1)}$)	0.00700***	0.00584**
	(0.00225)	(0.00218)
Δ(GenPen$_{i(t-2)}$)	0.00581*	0.00479
	(0.00292)	(0.00287)
Δ(GenPen$_{i(t-3)}$)	0.00483*	0.00431*
	(0.00250)	(0.00234)
Constant	-0.00217***	-0.00223***
	(0.000688)	(0.000690)

Universe Construction	**2G**	**Number of Phones**
Observations	750	750
R-squared	0.854	0.854
Robust Standard Errors in parenthesis		
*** p < 0.01; ** p< 0.56; * p < 0.1		

Robustness Test 3 – The Sample and Weighting of States: The Impact of the Five Largest and Five Smallest States

Our third test of the robustness of our analysis focuses on the sample and weighting of states (Table A-3, below) Again, our main regression specification is in column (1) and treats all 50 states weighted by population. Weighting by population is important for two reasons. First, it makes the results more directly applicable for national estimates. Second, the sample size for the Nielsen survey is small for several less-populated states. In Alaska, for example, the survey captured only two people in Q4 2006. Without weighting, none of the coefficients on the lags of ΔGenPen would be significant, as shown in column (2). It is apparent that neither large nor small states drive the results, since the coefficients on ΔGenPen are both more significant and larger when we drop the five smallest states (column 3) and the five largest states (column 4). In Q4 2006, the five largest states were Illinois, Florida, New York, Texas, and California; and the five smallest states were Wyoming, Vermont, North Dakota, Alaska, and South Dakota.

Table A-3: Test of Robustness –
Sample With and Without Five Largest and Five Smallest States

Variables	$\Delta(\log(Emp_{it}))$ (1)	$\Delta(\log(Emp_{it}))$ (2)	$\Delta(\log(Emp_{it}))$ (3)	$\Delta(\log(Emp_{it}))$ (4)
$\Delta(\log(Emp_{i(t-1)}))$	0.165***	0.107*	0.164***	0.120**
	(0.0519)	(0.0553)	(0.0530)	(0.0496)
$\Delta(\log(Emp_{i(t-3)}))$	0.196***	0.132***	0.198***	0.157***
	(0.0400)	(0.0373)	(0.0404)	(0.0409)
$\Delta(\log(Emp_{i(t-3)}))$	0.00729	-0.00966	0.0136	0.000579
	(0.0418)	(0.0478)	(0.0422)	(0.0481)
$\Delta(GenPen_{i(t-1)})$	0.00700***	0.00203	0.00898***	0.00680***
	(0.00225)	(0.00157)	(0.00256)	(0.00227)
$\Delta(GenPen_{i(t-2)})$	0.00581*	0.00110	0.00752**	0.00668**
	(0.00292)	(0.00122)	(0.00358)	(0.00276)
$\Delta(GenPen_{i(t-3)})$	0.00483*	0.000364	0.00648**	0.00462*
	(0.00250)	(0.00152)	(0.00294)	(0.00251)
Constant	-0.00217***	0.000156	-0.00234***	-0.00167***
	(0.000688)	(0.000936)	(0.000722)	(0.000605)

Sample	Full	Full	Without Five Smallest States	Without Five Largest States
Weighting	State Population	None	State Population	State Population
Observations	750	750	675	675
R-squared	750	750	675	675
Robust Standard Errors in parenthesis				
*** p < 0.01; ** p< 0.56; * p < 0.1				

Robustness Test 4 – Quadratic Effects

For our fourth test of robustness, we test for quadratic effects (Table A-4, below) Again, our main regression specification is in column (1). We also include as column (2) a regression where the differences of the squares of generational penetration, Δ(GenPen^2), as explanatory variables. The results show that the coefficients for these terms are small and not significant, so we conclude that quadratic effects do not influence our results.

Table A-4: Test of Robustness – Test for Quadratic Effects: Squared Terms

Variables	Δ(log(Employment$_{it}$)) (1)	Δ(log(Employment$_{it}$)) (2)
Δ(log(Employment$_{i(t-1)}$))	0.165***	0.164***
	(0.0519)	(0.0523)
Δ(log(Employment$_{i(t-3)}$))	0.196***	0.195***
	(0.0400)	(0.0405)
Δ(log(Employment$_{i(t-3)}$))	0.00729	0.00868
	(0.0418)	(0.0424)
Δ(GenPen$_{i(t-1)}$)	0.00700***	0.00698
	(0.00225)	(0.0158)
Δ(GenPen$_{i(t-2)}$)	0.00581*	0.0136
	(0.00292)	(0.0165)
Δ(GenPen$_{i(t-3)}$)	0.00483*	0.00116
	(0.00250)	(0.0160)
Δ(GenPen$_{i(t-1)}$)^2)	--	0.0000183
	--	(0.00476)
Δ((GenPen$_{i(t-2)}$)^2)	--	-0.00223
	--	(0.00471)
Δ((GenPen$_{i(t-3)}$)^2)	--	0.00116
	--	(0.00459)
Constant	-0.00217***	-0.00527***
	(0.000688)	(0.000611)

Observations	750	750
R-squared	0.854	0.854
Robust Standard Errors in parenthesis		
*** p < 0.01; ** p< 0.56; * p < 0.1		

Robustness Test 5 – Fixed Differences versus Long Differences for State Fixed Effects

Our fifth and final test for robustness focuses on state fixed effects. (Table A-5, below) Again, our main regressions specification is in column (1) and includes state dummies in a first differences fixed effects model with lagged quarterly differences of log employment and generational penetration explaining quarterly differences of log employment. Here, we also include as column (2) a long-differences model as presented in Griliches and Hausman (1984) to control for state fixed effects, rather than first-differences, and does not include state dummy variables. The long-differences model includes the longest period available, achieved here by differencing each variable's value from the value in the first quarter of our sample. The coefficient on ΔGenPen remains significant at the 5 percent level.

Table A-5: Test of Robustness – State Fixed Effects:
Fixed Differences Model versus Long Differences Model

Variables	Δ(log(Employment$_{it}$)) (1)	Δ(log(Employment$_{it}$)) (2)
log(Emp$_{i(t-1)}$) - log(Emp$_{i(t-2)}$)	0.165***	--
	(0.0519)	--
log(Emp$_{i(t-2)}$) - log(Emp$_{i(t-3)}$)	0.196***	--
	(0.0400)	--
log(Emp$_{i(t-3)}$) - log(Emp$_{i(t-4)}$)	0.00729	--
	(0.0418)	--
GenPen$_{i(t-1)}$-GenPen$_{i(t-2)}$	0.00700***	--
	(0.00225)	--
GenPen$_{i(t-2)}$-GenPen$_{i(t-3)}$	0.00581*	--
	(0.00292)	--
GenPen$_{i(t-3)}$-GenPen$_{i(t-4)}$	0.00483*	--
	(0.00250)	--
log(Emp$_{i(t-1)}$) - log(Emp$_{i1}$)	--	1.046***
	--	(0.00624)
GenPen$_{i(t-1)}$-GenPen$_{i1}$	--	0.00368**
	--	(0.00179)
Constant	-0.00217***	0.000834
	(0.000688)	(0.000870)

State Fixed Effects	Yes	No
Observations	750	850
R-squared	0.854	0.991
Robust Standard Errors in parenthesis		
*** p < 0.01; ** p< 0.56; * p < 0.1		

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