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What is This?

Innovation in the Green Economy: An Extension of the Regional Innovation System Model?

**Karen Chapple¹, Cynthia Kroll¹,
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Abstract

Policy makers increasingly look to green innovation as a source of job creation. Using the case of California, we argue that green innovation complicates traditional models of innovation and its role in economic development. This study uses secondary source data and a survey of 650 green and traditional businesses to define the green economy, identify innovation of products and services, and link innovation to sectoral and regional growth. The authors find that the type of innovation and its role varies widely by sector. The most environmentally challenged firms are among the most likely to innovate new processes, whereas new green innovative companies are more likely to respond to local and regional markets. Innovation does not necessarily foster growth. It is a boost to traditional firms, but emerging green firms may need additional tools and the support of local networks to transform new ideas and products to new markets.

Keywords

green economy, regional innovation, job creation, networks

Since Michael Porter (1996), AnnaLee Saxenian (1994), and others highlighted the potential of regional competitiveness, policy makers have promoted investment in innovation capacity as a critical strategy for economic development. Regional competitiveness comes from a collective process of experimentation, learning, and innovation, which help regions adapt to fast-changing markets and technologies (Cooke, 1998; Saxenian, 1994). This collective process might best be understood as a regional innovation system, a system in which firms and other organizations are systematically engaged in interactive learning through an institutional milieu characterized by embeddedness in a particular region (Asheim & Gertler, 2005).

One emerging regional innovation system is around the green economy, defined here as economic activity with the goal of reducing energy consumption or improving environmental quality. Much of the technology behind the clean energy economy has existed for decades (e.g., solar panels), but the onset of climate change has renewed firm interest in innovating new products, such as alternative fuels. It has also pushed firms to innovate their production processes for greater energy efficiency and environmental sensitivity. The emergence of new markets for green products, whether thermostats, fluorescent light bulbs, or organic food, has sped up the process of commercialization, or bringing newly developed products to mass production and markets.

What, though, is the green economy? Defined as economic activity that reduces energy consumption and/or improves environmental quality, the green economy encompasses both new and traditional sectors. Innovation in the green economy might thus occur through the creation of new products, the transformation of production processes, or the development of new markets. Energy provides a simple example. New industries, such as biofuels, may introduce new products that reduce dependence on traditional or dirty sources of energy. Traditional industries, such as utilities, may be changing the way they source power, relying more on renewable energy and alternative fuels (i.e., innovating how they produce energy). Individual households might install solar photovoltaic panels, thus joining an emerging market of energy consumers.

Using the case of California, the authors examine how innovation in the green economy fits—or complicates—traditional models of innovation and economic development. We construct the argument from two separate data sets: secondary source

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data on green businesses and a survey of 650 green and traditional businesses. We find that the type of innovation and its role varies widely by sector and firm type. The most environmentally challenged firms are among the most likely to innovate new processes, whereas new green innovative companies are more likely to respond to local and regional markets. Green and traditional businesses also differ in how they expect their innovation to translate into future job growth.

We begin by a brief overview of the literature on innovation. The next section offers definitions of the green economy and explains the methodologies used for collecting secondary source economic data and gathering surveys. After describing the green economy and innovation in California regions, we use multivariate (probit) analyses to explain the factors behind innovation. The article concludes with implications for theory and policy.

Regional Innovation: The Literature

Despite the extensive literature on innovation, there is little agreement on what fosters it and what its impacts are, especially at the regional scale. There is even confusion about what innovation is, because some see it as simple invention (which can be measured by patent activity) and others emphasize the importance of outputs or commercialization. For the purposes of this article, innovation will be understood as the introduction of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization, or external relations for the purpose of creating new value for customers and financial returns for the firm.

Market structure—typically measured as the distribution of firm size within the economy—shapes innovation, but the relationship is unclear; large firms may have more capacity to pursue research and development (R&D), but small firms have greater flexibility in making use of skilled labor (Freeman & Soete, 1997; Kamien & Schwartz, 1975). The mixed results on firm size and innovation may stem from differences between industries. Looking at the 4-digit Standard Industrial Classification (SIC) level, Acs and Audretsch (1987) find that large firms innovate better in industries that are capital-intensive and highly unionized, whereas small firms have an advantage in industries that use a large share of skilled labor. Thus we might expect large green manufacturers, for instance making train cars or solar panels, to be more innovative than small companies, whereas small firms doing precision manufacturing, such as environmental controls, would also be more innovative than firms performing less-skilled work.

Although it is well established that a large and diverse agglomeration of firms may help foster innovation, not all types of innovation need agglomeration to thrive (Brouwer, Budil-Nadvornikova, & Kleinknecht, 1999; Oakey, Thwaites, & Nash, 1982; Simmie & Sennett, 1999). Core regions tend

to generate more product innovation, but peripheral regions specialize in process innovation and innovate more continuously (Keeble, 1997). The competitiveness of peripheral regions in terms of process innovation may be due to an active effort to compensate for lack of external resources in such areas, including consciously pursuing more R&D (Vaessen, 1993).

At present, there is a (relative) consensus that innovation at the regional level is best captured as a system (a regional innovation system [RIS]), where multiple actors and institutions must interact to produce, diffuse, and use new and economically useful knowledge (Cooke, Gomez Uranga, & Etxebarria, 1997; Edquist, 2005; Lundvall, 1992; Nelson, 1993). An established literature shows the role of universities in developing and sharing intellectual property and talent (Jaffe, 1989; Saxenian, 1994). Firms may also draw on the financial resources of venture capitalists, on the skills of other firms, consultants and suppliers, and even source product development from customers. Although most acknowledge the importance of private sector involvement in the RIS generally, the literature is largely silent on the role of markets. Because the process of innovation relies heavily on tacit knowledge (Pavitt, 2002; Polanyi, 1958; von Hippel, 1988) that is heavily imbued with meaning arising from the social and institutional context in which it is produced, and therefore, difficult to exchange over long distances (Gertler, 2005); regions (and spatial proximity) play a critical role in fostering innovation (Asheim & Gertler, 2005; Cooke et al., 1997; Cooke, Heidenreich, & Braczyk, 2004).

Yet the regional innovation systems literature may over emphasize the importance of external resources and spatial proximity. The innovation system itself may not be operating well if it fails to connect diverse actors and instead fosters close ties between similar organizations resulting in "lock-in" (Tödtling & Trippl, 2005). Local information spillovers may not play as critical a role as thought, given the continued importance of a firm's internal technological expertise and the reluctance of some firms to collaborate (Freel, 2000; Gordon & McCann, 2005; Rothwell & Dodgson, 1991). Finally, regional embeddedness may impede innovation, as large dowager firms exert power over investment and information flows (Christopherson & Clark, 2007). Clearly, innovation operates at multiple levels, and industries differ in how they use global, national, and regional resources in their innovative processes (Asheim & Isaksen, 2002).

Existing literature sheds little light on the relationship between innovation and regional (as opposed to national) economic growth. That innovation leads to economic growth (in terms of productivity and jobs) is well established at the national level (Brouwer, Kleinknecht, & Reijnen, 1993; Mansfield, 1972; Nadiri, 1993; Romer, 1986; Solow, 1956). Researchers and policy makers interested in regional economic development seem to have adopted this finding uncritically; yet there are reasons to question the connection. The major regional economic theories, from growth poles to product cycles to flexible

specialization to competitive advantage, are equally vague about how innovation will translate into job growth that can be captured locally (Plummer & Taylor, 2001). High-technology clusters, despite generating high levels of innovation (as measured by patents), are more likely to foster new businesses than job gains (Feser, Renski, & Goldstein, 2008). Christopherson and Clark (2007) contend that it may even be in the interest of transnational corporations to crush innovation in smaller firms and send product development and production to regions with lower labor costs.

The mixed literature on market and urban structure suggests that there will be significant variation in regional performance, depending on the sector: We cannot expect the green building industry to innovate in the same way as biofuels. It is likely to be difficult to discern a relationship between innovation and job growth, especially given the time frame and context (business cycle trough) in which we are looking at job growth. Finally, the regional innovation system model may work well for some sectors—for instance, those dependent on university-led R&D—but not for others. In particular, green industries innovating in process (such as utility companies changing the way they source energy) or market (such as green building firms building new market niches) may not conform nicely to the RIS model.

Our research design focuses on a few specific aspects of the innovation systems described in earlier literature to see how green innovation sheds light on the model. The descriptive sections of the article identify concentrations of green business employment and compare innovative activity as measured by both investment and patents with employment agglomerations and employment growth rates. A survey directed to green firms, traditional firms, and environmentally challenged firms allows further examination of the role of local networks, intellectual property and talent, and social and institutional context in green innovation and expected firm growth.

Data and Method

Although it seems that nearly every week brings a new study trumpeting the potential for green jobs, there have been few systematic attempts to measure local or regional economic activity in the green economy, let alone understand how green businesses work. Two notable exceptions are reports by the Pew Charitable Trust (2009) and the California Economic Strategy Panel (Collaborative Economics, 2008). Both studies, which rely heavily on research by Collaborative Economics (a Silicon Valley consulting firm), develop typologies of the green economy and count jobs using existing industry codes.

Based on a review of 25 other regional and national reports on the green economy, we identify 18 different industry sectors considered part of the green economy, diagrammed in Figure 1.[1] Each sector contains multiple industries, and not all firms in all industries are necessarily green. The figure also highlights how frequently each industry sector is mentioned in the reports, with the darkest shades representing the sectors cited most frequently.

The diagram presents the range of green business categories along two axes. The vertical axis shows the range from traditional businesses, such as utilities and professional services that are greening their operations, to businesses in emerging industries, such as nanotechnology research, solar panel manufacturing and ecotourism, often referred to as cleantech. Since they are late in the product cycle, the traditional businesses are more likely to be innovating in process, while the emerging industries are innovating new products.

On the horizontal axis, businesses move from those that produce green products, such as manufacturers and food processors, to those that sell green products or participate in the green-lifestyle economy, such as farmer's markets and local park maintenance operators. Business categories located in the middle of the horizontal axis contain both production and consumption aspects. Within the green economy, businesses interact with and are influenced by the government agencies, universities, nonprofit organizations, unions, utilities, and trade associations in the regional innovation system (shown at the bottom of the diagram). Innovation may occur in any industry; however, as we discuss in the next section, it is easier to measure and track in some than others. For instance, cleantech R&D may register new patents, a fuel cell manufacturer may commercialize its new product successfully, and green building firms may attract new customers to innovative energy-reducing designs—but only the patents can be readily tracked. Our firm survey addresses these measurement constraints in the study of green innovation.

California is a near ideal laboratory for the study of green innovation for three reasons. First, it hosts perhaps the most famous innovative milieu of all, Silicon Valley, a region that continues to generate lessons in innovation for regions throughout the world. Second, it has an entrepreneurial state government with some of the most stringent new climate change legislation in the nation, which has spurred the largest concentration of green innovation in the country (Collaborative Economics, 2009). For instance, in 2006, the California Assembly passed AB 32, the California Global Warming Solutions Act, which establishes the first comprehensive program of regulatory and market mechanisms to reduce greenhouse gases. In its implementation, which is currently taking place, AB 32 (and its sister land use planning bill, SB 375) is requiring substantial changes in how California businesses—and regions—operate. Third, its regions, which include 34 metropolitan areas, range from some of the most affluent (e.g., San Francisco) to the most distressed (e.g., Merced) in the country. Thus, looking at California allows us to study how different types of regions with different levels of resources innovate under the same state economic development climate.
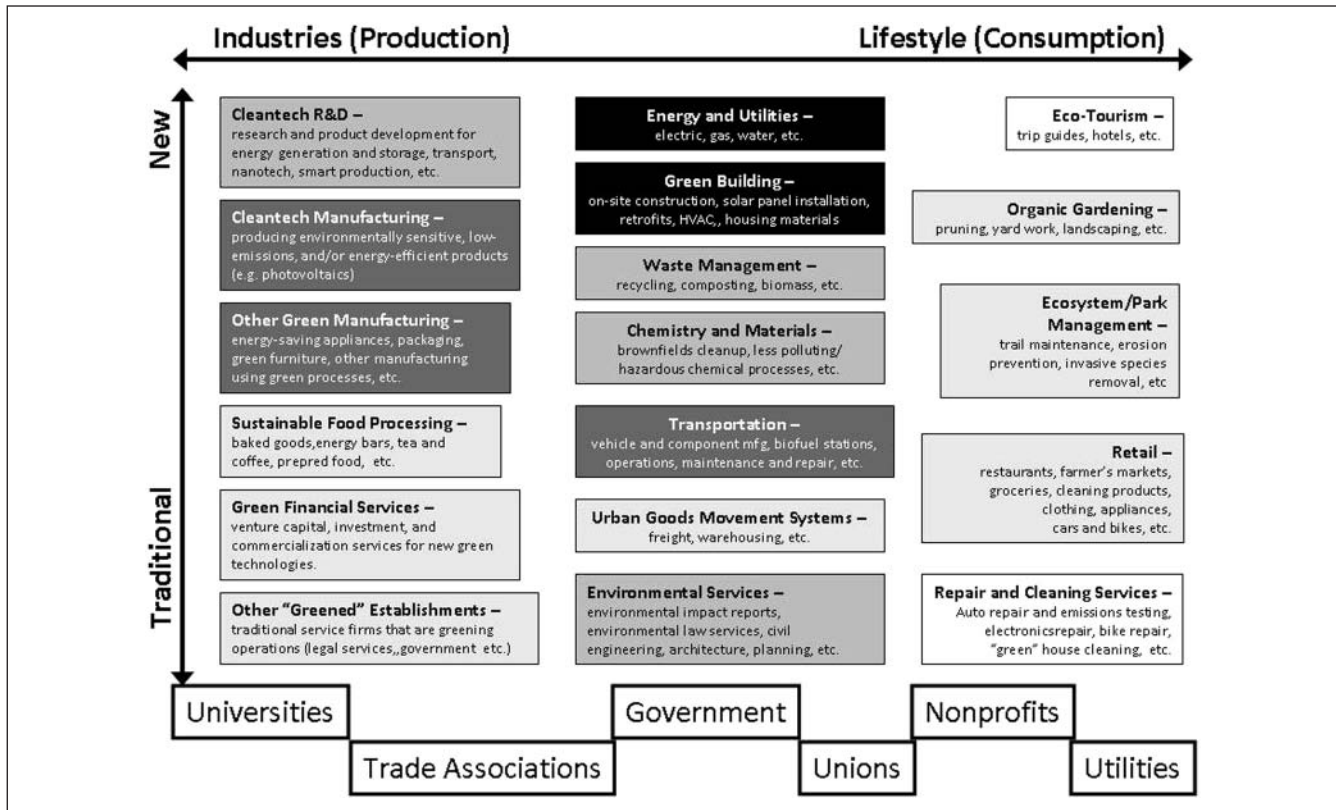
Figure 1. Defining the green economy

Using NETS Data to Measure Green Business

Economists and planners have had little experience in measuring economic activity in this nascent green arena. Several previous studies have relied on the National Establishment Time-Series (NETS) database, a private sector–generated database that combines annual Dun and Bradstreet individual establishments' entries into a time-series from 1990 through 2008. This database provides detailed data on individual establishments over time, from establishment births (beginning in 1989) through current operations or deaths. It includes an 8-digit SIC for each establishment, providing much more detailed industry information than do the 6-digit North American Industrial Classification Codes.[2]

NETS has specific strengths and weaknesses. By providing data at the establishment level rather than an aggregate geographic unit of analysis, it allows ready analysis of how individual establishments change over time and makes it possible to examine adaptation of product lines, start-up activity, and gazelles (or firms growing rapidly in sales). Shortcomings include costs, accuracy, and consistency over time (see Kroll et al., 2010 for a detailed discussion).

We used an iterative process to define 8-digit SIC codes. From the NETS database we drew establishments from 8-digit SICs used in earlier studies. We added lists of green businesses

obtained from local cluster initiatives and green certification programs, manually excluding businesses that are green certified for branding reasons rather than because of product or process (for instance, national banks that recycle paper). We used the 8-digit SIC code for these businesses to expand our initial list of codes. This iterative process yields a list of 194 different SICs related to the green economy, rather than 75 as in previous studies. We organized these industries into six sectors[3]: green building, energy research and services, environmental services (including a variety of firms from environmental consultants to hazardous waste testing), recycling and remediation, green manufacturing (directly related to improving the environment or reducing energy consumption such as water filters and thermostats), and green transportation (transit, electric vehicles, and nonmotorized transport). In essence, only green-producing industries were included in the analysis, since it is not possible to identify green lifestyle sellers using this system.

Even at the 8-digit SIC level, defining green remains challenging. "Green" codes may include activities that are not green; for example, either hybrid or traditional vehicles might make use of Battery Charging Alternators and Generators (36940100). In other cases, a green activity may cross over several different codes; for instance, biofuels firms may be found under SIC 28690400 (Fuels), 49539905 (Recycling,

Waste Materials), 36749901 (Fuel Cells, Solid State), and even 52110301 (Energy Conservation Products).

Measuring Innovation

To assess the level and characteristics of innovation in regions, we used a model from the *Measuring Regional Innovation* report (Council on Competitiveness, 2005) that divides the innovation process into three interrelated phases: idea generation, idea development, and commercialization. Unfortunately, not all innovation metrics are available on a sectoral basis; for instance, though we know the number of angel networks in each region there are no data on financing and other support they are providing for the green economy, unlike venture capital, which is documented in detail. Thus, we only include metrics that are specifically green or cleantech related.

To represent idea generation, we used data on clean-tech patents issued in California, purchased from the U.S. Patent and Trademark Office (USPTO) via a third-party data provider. To identify patents that covered green products or clean technologies, we searched the abstract field of each record for the following keywords, which we organized into the following eight categories: alternative fuels, energy management, fuel cells and vehicles, green building products, other renewable energy, pollution control, recycling, and solar.

To reflect idea development, we looked at Small Business Innovation Research (SBIR) grants, Small Business Technology Transfer (abbreviated as STTR) grants, venture capital, and green start-ups. SBIR and STTR grants data came from the U.S. Small Business Administration's TECH-Net database, using similar cleantech categories as in the patent search. We collected venture capital investment data from the Thomson Financial VentureXpert database, searching under the categories of alternative energy, energy conservation, and energy management. We use the NETS to observe the growth of new establishments over time by industry. An establishment is a start-up if it has not appeared in the time-series database previously and if it is not a branch or franchise of an existing firm located anywhere in the United States.

Finally, to represent commercialization, we measured the presence of green gazelles by counting the number of firms that have increased their sales at an above average rate. Specifically, we define an establishment as a gazelle if its sales growth over a 3-year period was in the top quintile (20%) relative to other establishments within its own broad industry sector.[4] To create a green innovation ranking for California regions, we created a composite index that weighted each of these three components of the innovation process as one third of the total.

Business Survey Structure

The business survey focused on six study regions: Los Angeles, San Diego, Silicon Valley, the East Bay, the Inland Empire, and the Upper San Joaquin Valley, a three-county region extending from Stockton to Merced. These regions were selected to represent California's four most innovative green regions, along with two distressed regions typical of California's Central Valley. About 15% of our respondent sample actually came from outside these six regions, mostly from adjacent metropolitan areas such as San Francisco and Orange County.[5] Thus the survey broadly represents California's largest metropolitan areas as well as its inland valley, but likely underrepresents some coastal areas, the mountain regions, and the far northern counties.

The survey consisted of three separate samples: green businesses, traditional businesses, and businesses listed in the U.S. Environmental Protection Agency's Toxic Release Inventory (which emit significant amounts of toxic chemicals or greenhouse gases other than carbon dioxide). To develop the green survey sample, we began with a list of green establishments active in 2007, with five or more employees, from the NETS (8-digit SIC code-based definition). We then added records from the Build it Green database of certified green businesses in California. We gathered e-mail addresses for each record through web searching, obtaining information for 1,513 (35.4%) of the universe of green businesses in the case study areas.

For the traditional business survey, we used a stratified random sampling procedure to select from the NETS, a parallel or matched set of businesses not identified as green. For instance, we sampled a variety of regular construction and manufacturing firms, as well as other traditional sectors likely to be affected by environmental regulations, such as transportation and agriculture. The Toxic Release Inventory (TRI) sample came from the Environmental Protection Agency's 2009 release, which includes facility public contact information. We sent the survey to the full list of TRI businesses with e-mail addresses available or readily obtainable.

All the survey instruments asked questions about regional competitiveness, orientation toward green activities, impact of state and federal legislation, innovation, training, and social networks (as well as background information). In addition to multiple-choice responses, both surveys provided extensive opportunities for open-ended responses.

A combination of e-mail invitations, postcards, and follow-up phone calls were used to maximize the survey response rate. The principal method for survey collection, however, was the same for each of the three distribution types: an online survey tool, Surveymonkey.com. Each respondent was contacted three times over a period of 3 weeks, many through mixed modes. The entire survey took place between April 15 and July 15, 2009. A total of 5,273 businesses were e-mailed and asked to participate in the survey. In an effort to increase the response rate among green businesses and diversify the survey sample, postcard invitations were sent to 2,382 additional green businesses. Follow-up telephone phone calls to the full sample were the last effort made to encourage businesses and organizations to participate in the survey. This method was targeted only at green businesses in regions with low response rates; in total, 273 businesses were called.
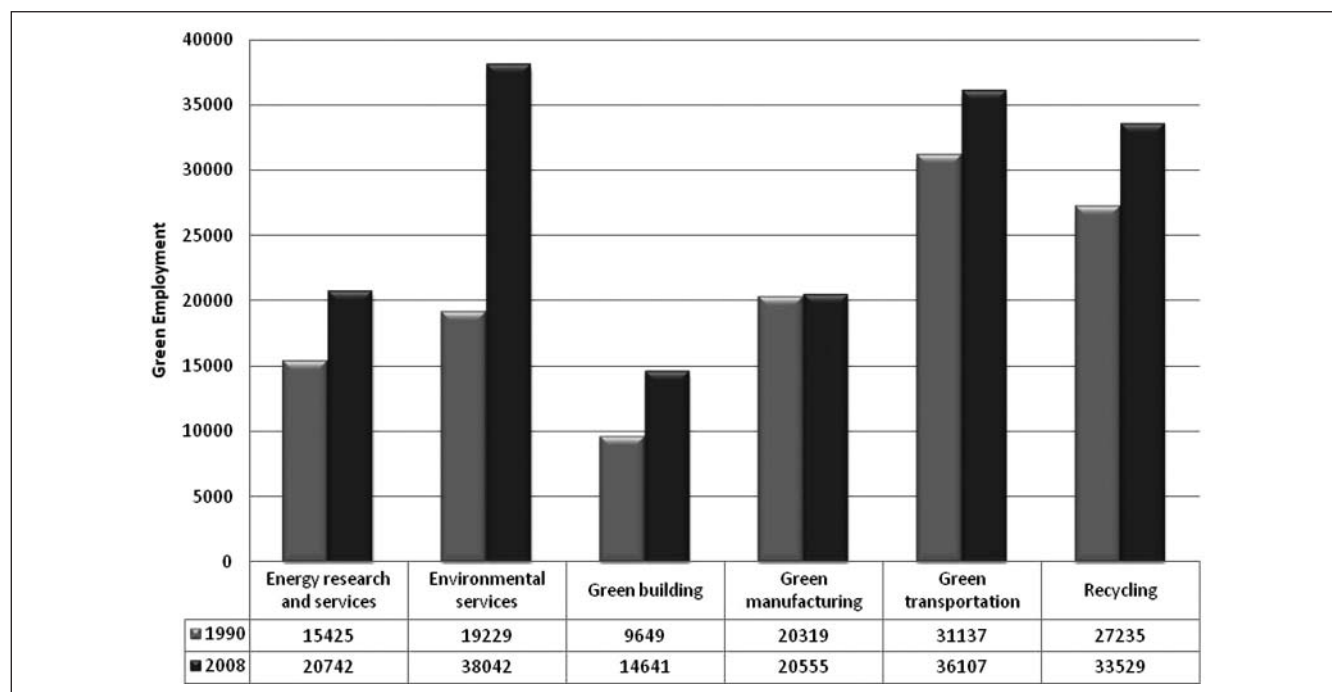
Figure 2. Green employment in California by Sector, 1990 and 2008
Source: NETS (National Establishment Time-Series) data; calculations by the authors.

In total, 7,655 various businesses and organizations were approached. Of these, 369 surveys were either returned or not delivered. These businesses were removed from the total to create the survey universe (*N*) of 7,286 businesses. Among these, 649 different businesses responded, for a total response rate of 8.9%. The e-mail distribution method was by far the most effective, generating a 15.8% response rate from the green businesses. The TRI businesses were also surprisingly willing to participate, with a 13.6% response rate. Traditional businesses had a 7.3% response rate. The postcard and telephone methods were substantially less successful, with response rates of 5.0% and 3.8%, respectively.

An Aggregate Look at Green Sectors, Job Growth, and Innovation

We used descriptive statistics and trends at the state and regional levels to examine where different sectors cluster, how innovation is concentrated geographically and by sector, and growth of green sectors in the context of regions and the statewide economy. This provides the background for the regression analysis in the next session, which then examines how these factors interact to produce innovation and job growth.

Overview of California's Green Economy

In 2008, there were 12,253 green establishments in the NETS California database, which collectively employed

163,616 workers across six distinct green economic sectors (see Figure 2). Green economic activity makes up a very small percentage of businesses and jobs (less than 1% of state employment). This is not surprising given the size and diversity of California's economy, as well as the compromises we make in using the NETS-based definition of the green economy. Businesses engaged in providing environmental services, including such industries as hazardous waste testing and environmental consulting, made up the largest share of all green establishments (38%) in 2008 and had more than 38,000 employees. Recycling establishments comprised roughly one quarter of all green business (26%) and employed close to 33,500. Transportation activities account for only 13% of establishments but employ more than 36,000. Despite their importance in bringing export dollars and attracting R&D investment, green manufacturers and energy research and service companies represented only 8% and 6% of establishments, respectively.

Figure 3 indexes employment over time to employment levels in 1990. Green employment grew by 33% compared with 22% growth in California's total employment between 1990 and 2008, but the rate of change varies over time. The green economy grew more rapidly than the state as a whole in the early and mid-1990s, with the overall state trend picking up the pace in the tech boom years of 1999 to 2002. The number of green jobs dropped more slowly than statewide employment in 2002 to 2005. In the early part of the 2007 economic crisis, green employment grew as total employment declined.
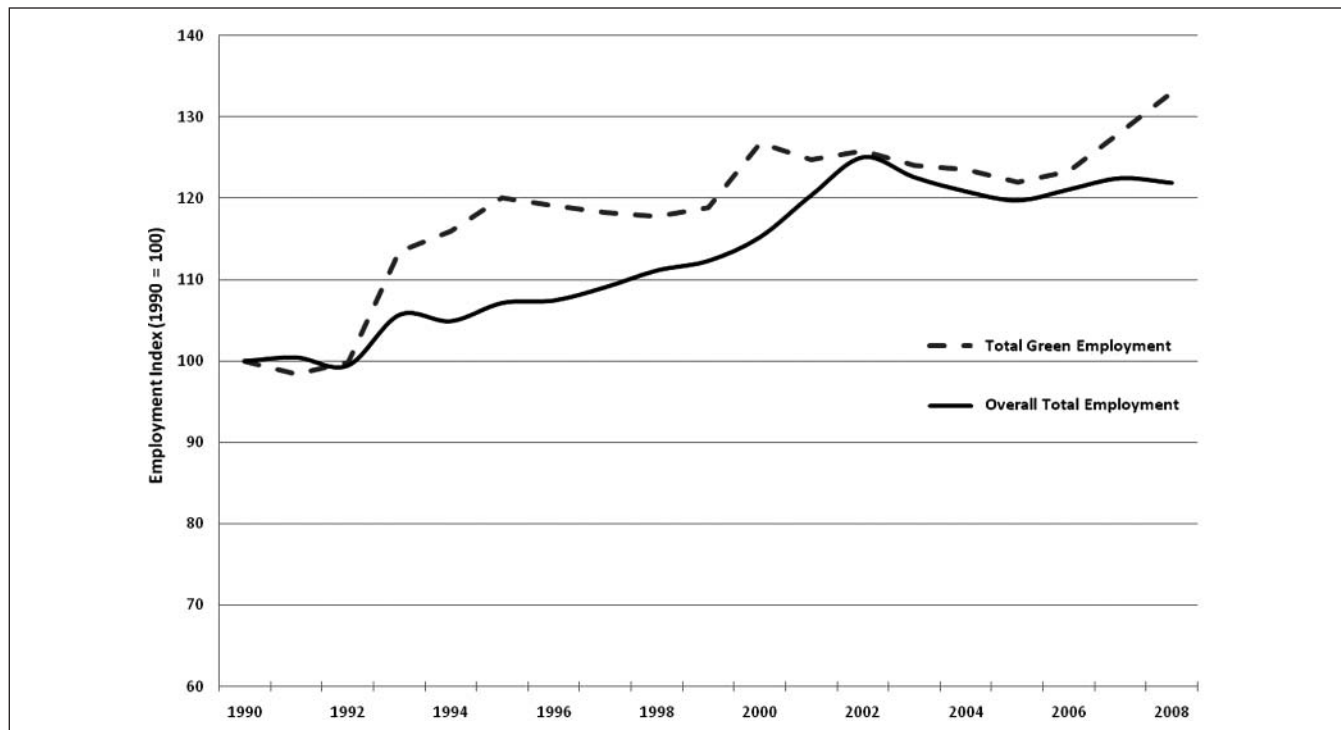
Figure 3. Index of employment change in California, green sectors versus overall, 1990-2008
Source: NETS (National Establishment Time-Series) data; calculations by the authors.

Employment growth rates vary among green sectors. Fastest growing sectors include environmental services, which almost doubled between 1990 and 2008; green building, with fewer than 15,000 jobs but which grew by 52% since 1990; and energy research and services, expanding by one third and including three nationally funded research labs in the East Bay, Lawrence Livermore National Lab, Sandia National Lab, and Lawrence Berkeley National Lab, housed at University of California–Berkeley.

Location and Growth Within California

Table 1 shows concentration of green employment by both absolute numbers of jobs and green job share relative to total California job share (the location quotient). The five largest California metropolitan areas[6] have close to 70% of green jobs (compared with 62% of total employment). Los Angeles had the largest number of total green jobs in the state, primarily in manufacturing, transportation, and recycling. This reflects Los Angeles's traditional economic advantages in goods production and logistics. The area's relative share as measured by the location quotient is just below 1, showing it has slightly less than the expected share of green jobs relative to the size of the economy. The densest concentration as measured by location quotient can be found in the East Bay (Alameda and Contra Costa Counties). With three large national laboratories, it dominates the energy research and services sector, ranks second on total green employment, and also has large concentrations of jobs in environmental services. San Diego, San Francisco, and Sacramento regions also had shares of green jobs exceeding their shares of total jobs (location quotients greater than 1). Silicon Valley's total number of jobs in green industry sectors was surprisingly low compared with other large regions in California, though it is a leader in green building.

The fastest growth in green jobs has been in Central Valley places and in the Riverside–San Bernardino metropolitan area. After describing innovation trends, we return to the regional differences to compare innovation and growth trends.

Measures of Innovation in the Green Economy

Patents. Since 2000, there were 172,279 patents assigned to companies, universities, or individuals located in the state of California. Of this figure, only 1,096 were classified as cleantech based on our analysis of each patent's abstract. The number of green/cleantech patents represents a small share of all patents (0.6%) and, despite the recent public attention paid to the green technologies, the number of patents assigned remained relatively steady since 2000.[7]

Patent activity for green products and/or clean technologies was distributed evenly across five of the eight cleantech market segments: solar technology, fuel cells, hybrid vehicle technology, alternative fuels, and green building products. By region, Los Angeles (led by CalTech and the aerospace industry) was

Table 1. Top 10 Metropolitan Regions, Ranked by Green Jobs in 2008

Region	Green Jobs, 1990	Green Jobs, 2008	Average Annual Growth Rate 1990-2008 (%)	Share of Green Jobs 2008 (%)	Share of Total Jobs 2008 (%)	Green Job Location Quotient 2008	Most Concentrated Sector by Region (Location Quotient)
Los Angeles	38,354	39,875	0.20	24.40	28.20	0.86	1.48, Green manufacturing
East Bay	23,312	30,876	1.60	18.90	7.10	2.67	10.5, Energy research and services
San Diego	11,691	18,220	2.50	11.10	9.00	1.24	1.5, Environmental services
Orange County	9,151	13,551	2.20	8.30	10.60	0.78	1.3, Environmental services
Riverside–San Bernardino	6,818	11,781	3.10	7.20	7.60	0.94	1.4, Recyling/remediation
San Francisco–San Mateo–Marin	9,880	11,352	0.80	6.90	6.70	1.03	2.1, Green transportation
Sacramento	4,544	8,834	3.80	5.40	5.10	1.06	1.5, Environmental services
Silicon Valley	4,151	6,121	2.20	3.70	5.90	0.64	2.8, Green building
Upper San Joaquin	1,716	3,015	3.20	1.80	2.80%	0.67	1.0, Green building
Fresno	1,555	2,427	2.50	1.40	2.10	0.69	1.4, Green building

Source: NETS (National Establishment Time-Series) data; calculations by the authors.

awarded the highest share of cleantech patents overall, and specialized in solar and fuel cell technology. The East Bay, which is home to University of California–Berkeley and several large petroleum companies, led the state in alternative fuels and was tied for leading region status for recycling and pollution control technology. Silicon Valley was less specialized overall than Los Angeles or the East Bay, but still led the state in two smaller cleantech categories, other renewable energy (which includes wind turbines and geothermal energy), and energy management (e.g., smart grid) technologies. Overall, 15 entities account for 29% of all California cleantech patents between 2000 and 2008, suggesting that large, well-established actors take a significant role in innovation in California's green economy. In particular, the involvement of universities such as the University of California and the California Institute of Technology suggests that the resources required to conduct research and develop new energy-related technologies may be so high that small firms and individual inventors are not yet leading the process of innovation in the green economy.

Venture capital investments. Unlike issued patents, which measure the final outcome of several years worth of research and application processing time, venture capital flows capture the degree to which investors are taking risks to back new ideas, concepts, or business plans. Thus as a metric of innovation, venture capital is a more volatile and dynamic measure of changes in investors' preferences.

Over the 8-year period between 2000 and 2008, a total of $154.9 billion of venture capital was invested in California firms across all sectors of the economy. The trend in overall venture capital investment in California is indicative of the dot-com bust beginning in 2001, as venture capital investment fell from $44.5 billion in 2000 to $9.3 billion in 2003. Investment gradually recovered to $16.2 billion in 2008 (see Figure 4). As was also the case with patents, clean technologies received

only a very small share of total venture investments during this period, or $1.6 billion (1.1% of total). Unlike patents however, the trend in venture capital investments surged recently, rising from nearly 0 in 2005 to $1.1 billion (7% of total) in 2008. The spike in recent venture capital activity is evidence of growing investor and entrepreneur interest in clean technologies.

Of the venture capital funds invested in clean technologies, the majority between 2000 and 2008 were invested in just three sectors—more than two thirds in solar technologies, 18% in energy management, and 9% in wind energy. Despite globalization, proximity to the venture capital source remains important. More than 30% of California cleantech venture capital funding was concentrated in Silicon Valley, with the next highest shares in the East Bay (16.4%), San Francisco (16.1%), and Los Angeles (15.0%).

Small business innovation research grants. The third metric of innovation is the distribution of Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Grants made by the U.S. Small Business Administration. SBIR grants go directly to small businesses whereas STTR grants are awarded to joint ventures between small businesses and nonprofit research institutions. Unlike patents or venture capital investments, which measure innovative activity undertaken strictly by private parties, SBIR and STTR grants involve the discretion of a government agency, and thus may potentially be influenced by political concerns. Nonetheless, the distribution of such grants and the total amount of grants awarded is a measure of where small companies engaged in bringing a new product of service to market are located.

Between 2000 and 2008, the SBA made 7,097 SBIR grants across Phases I and II, totaling more than $2.5 billion; during the same period, there were 909 STTR grants totaling $229 million. Of this amount, only 102 SBIR grants and 41 STTR grants were made to firms or ventures developing clean
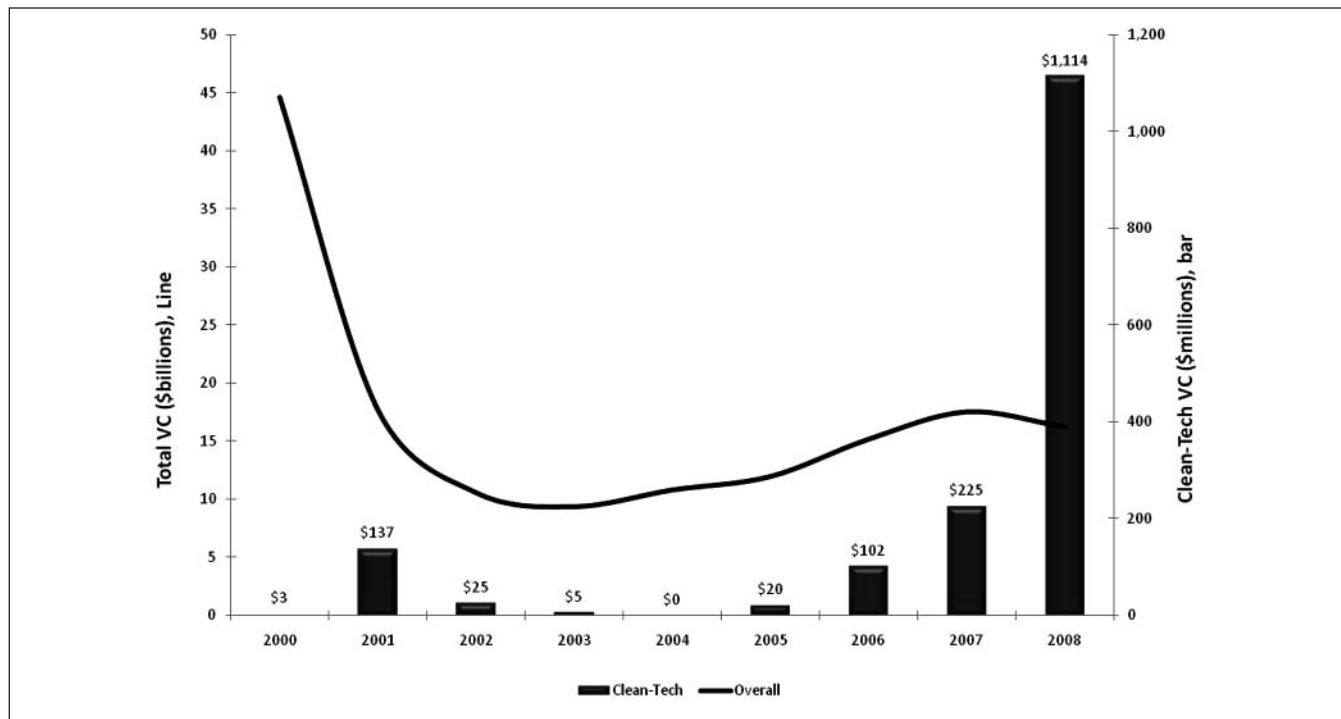
Figure 4. Venture capital investments in clean technologies and overall, 2000-2008
Source: Thomson Financial VentureXpert database; calculations by the authors.

technologies, for a total of $46.8 million over this 8-year period (1.7%). Firms in the solar business received the majority of SBIR/STTR funding (52%), with other cleantech (such as thermal energy, smart grid applications, solar-driven manufacturing processes, and temperature control devices) garnering 21%, and alternative fuels at 13%. One third of the grants went to businesses in the Los Angeles region, with San Diego County having the next highest share (17.8%).

Start-ups. The previous indicators of innovation each measure activity undertaken by existing firms or institutions in California. However, a critical aspect of innovation is the growth of new firms in emerging industries. Using a time period similar to that of our other innovation metrics, 2000 to 2007, there were a total of 7,231 green start-ups in California, a figure that is a small fraction (0.4%) of the 1.8 million start-ups throughout the economy, a small share even compared with the green economy share of the overall state economy.

Figure 5 tracks green and total start-ups in the state by start-up year. The trend in new establishment start-ups in the green economy fluctuates significantly by year since 1990, with a sharp decline in the boom years of 1996 to 1999 and a peak in 2002. This trend is consistent with overall economic trends; entrepreneurs choose to start new businesses in times when there are fewer overall opportunities in the labor market. Most recent years have also seen an increase in green start-ups, which may be consistent with increased interest in the green economy, as also indicated in the analysis of venture capital flows, but

could also be one more swing in an overall volatile pattern of green start-ups. The location pattern of green start-ups mirrors that of start-ups overall in California but with a slight difference: the three regions with the largest share of the state's start-ups (Los Angeles, Orange, and San Diego counties) have a disproportionately low share of green start-ups, while traditionally less dynamic metros such as the East Bay, Sacramento, and the Inland Empire are gaining a disproportionately large share of green start-ups.

Gazelles. Since 2002, the green sector has spawned a greater share of gazelles than the economy overall, and that trend has accelerated in the past 2 years. Figure 6 shows the share of green establishments that are gazelles relative to the share of all establishments that are gazelles. As with start-ups, the location pattern of green gazelles does not exactly correspond to that of gazelles overall in the state: for instance, Los Angeles has 26% of the state's gazelles, but just 21% of its green gazelles, whereas the East Bay, with 7% of the state's gazelles, has 11% of its green gazelles.

Comparing Green Innovation and Regional Concentration

We next examine the distribution of innovative activity across California as well as the geographic trends in innovation and the green economy. Table 2 lists all of the five innovation metrics discussed above for the 10 most innovative of California's
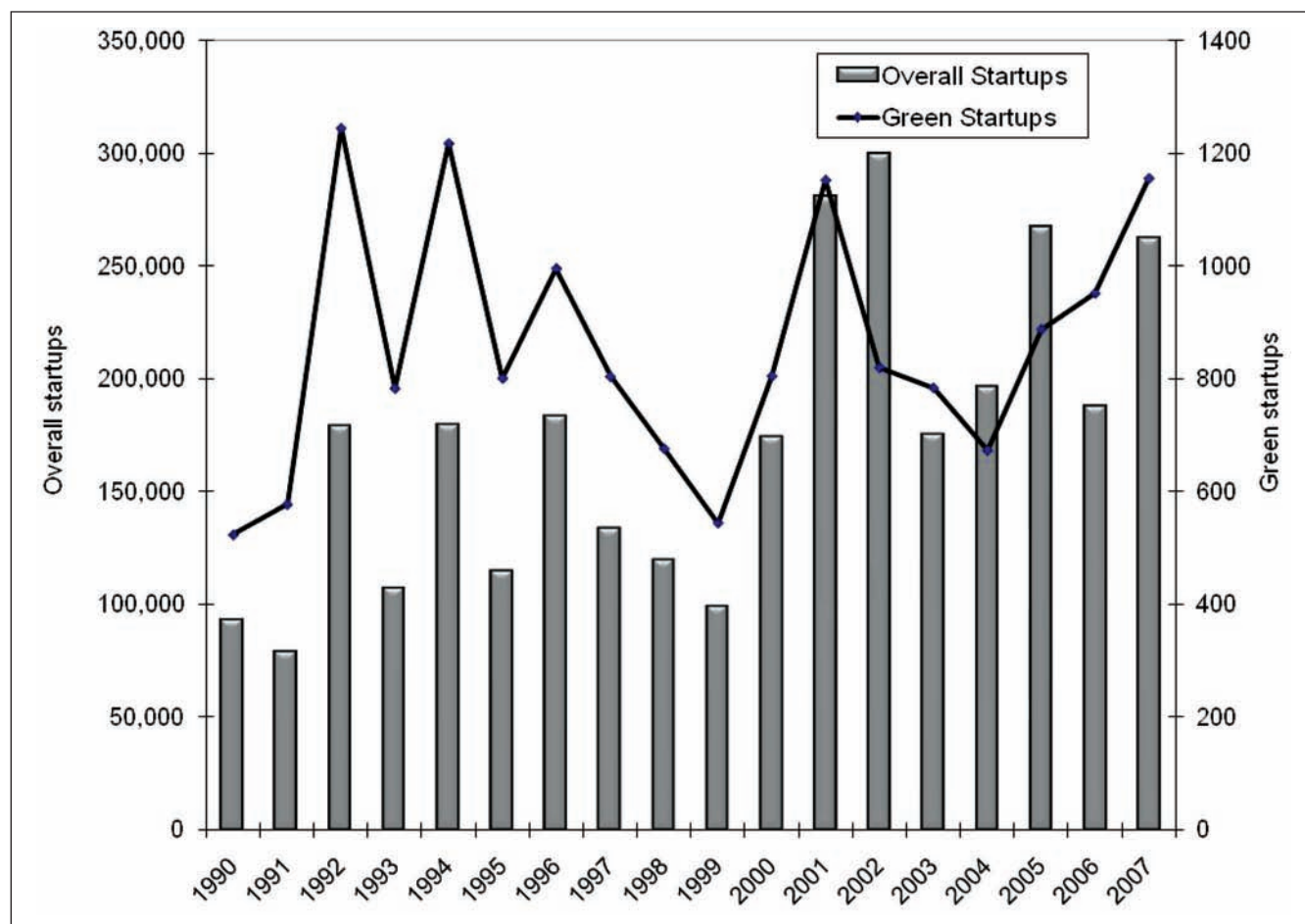
Figure 5. Green start-ups by year, 1990-2007
Source: NETS (National Establishment Time-Series) data; calculations by the authors.

34 metropolitan regions. In each case, the raw numbers for the green/cleantech metric are listed (e.g., number of cleantech patents, total cleantech venture capital investment), followed by the share of California's cleantech innovation in that category. The final columns compute the regions' cleantech ranking as well as their ranking in innovation overall in California.

As was the case in other innovative sectors (e.g., information technology and biotech), innovation in the green economy is highly concentrated in a few of California's largest metropolitan regions. For example, Silicon Valley garnered 31% of total cleantech venture capital investments and 36% of overall venture capital in California. Los Angeles, the East Bay, and San Diego also have large concentrations of other measures of cleantech innovation including patents, SBIR/STTR grants, firm start-ups, and green gazelles. Outside of these large, innovative regions, there is very little innovative activity as measured by these broad metrics.

It is interesting to note that although Los Angeles ranks as the most innovative region in the state on our cleantech ranking,

from an industry perspective, the majority of its green jobs are outside of those sectors that are closely linked to R&D. The East Bay, in contrast, although ranking only third in Table 2, is strong in patent activity relative to its share of green jobs and in all other measures except SBIR/STTR grants relative to its share of overall jobs.

Figure 7 addresses the relation between innovation and job creation in these regions, plotting all 34 of California's metropolitan regions according to their composite cleantech ranking on the vertical axis and the annual average growth rate of green jobs between 1990 and 2008 on the horizontal axis. The size of each region's bubble reflects its 1990 green employment level. This figure bears out the observation made above that innovation is highly concentrated in a few large metro areas, including Los Angeles, San Diego, the East Bay, and Silicon Valley. Although there are several smaller regions that compare favorably on job growth, their increase is on a very small base. This figure shows no clear link between innovation and job growth. Other factors, such as overall growth of
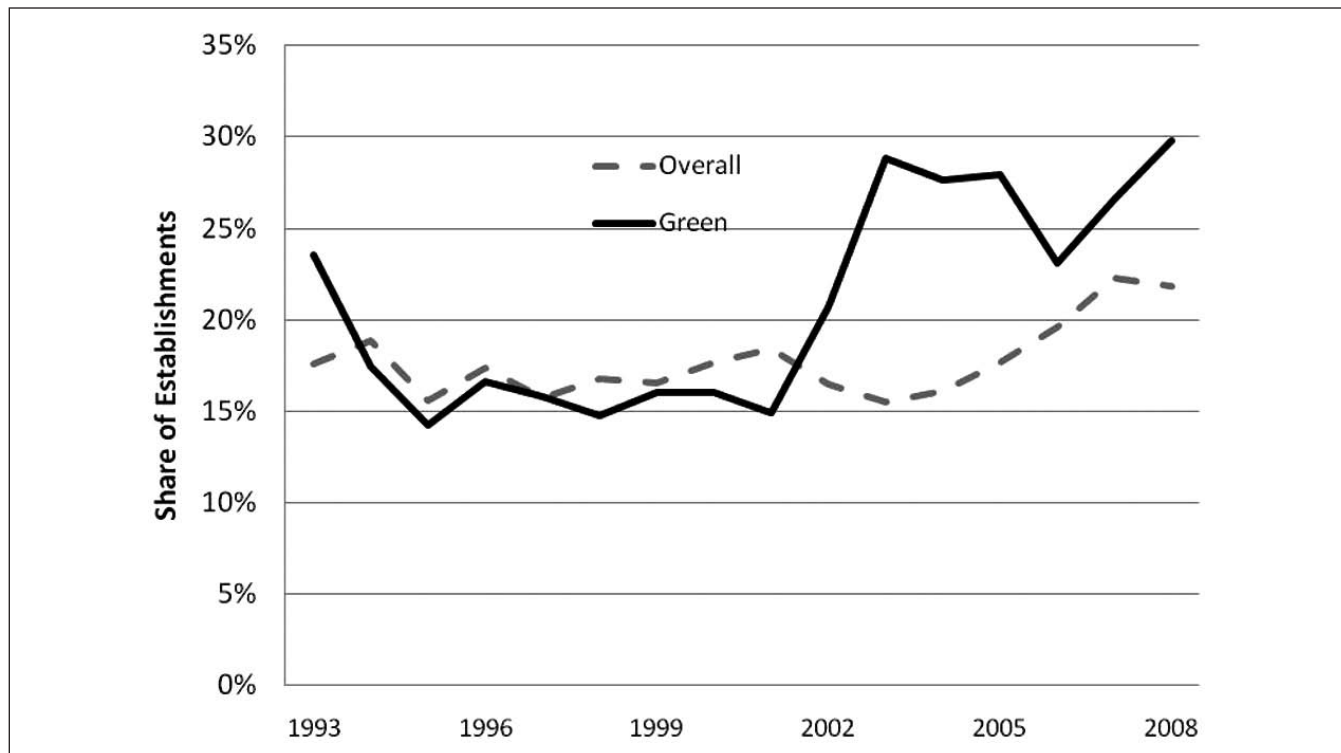
Figure 6. Change in share of green gazelles versus all gazelles
Source: NETS (National Establishment Time-Series) data; calculations by the authors.

population, industry mix, and other economic factors, likely interact with these results. We turn next to a more in-depth examination of green innovation using our survey results.

Describing Green Innovation in California: Survey Results

The survey was designed to examine innovation in green sectors and its relationship to firm internal, external, and location characteristics, as well as expectations for growth. Survey responses also address policy concerns associated with the green economy and environmental regulation. Green, traditional, and TRI businesses responded to a similar set of questions. We first present descriptive statistics of the major findings. We then use statistical techniques to test the significance of location and network characteristics in the context of sectoral and firm structural variations. Given the sampling process, with heavy weighting toward green and TRI firms and the low response rate from traditional firms, the results should be seen as suggestive and indicative of further research directions, rather than definitive.

Product Versus Process Innovation

We examine two types of innovation—product and process. The survey asked each business whether it had innovated a new product or service in the past 3 years, and if so, to describe it. We also asked if firms had changed the way they operate to reduce environmental impact or meet environmental regulations. Incorporating changes in the production process may mean processes as simple as reducing energy use or as innovative as applying new technologies, recently commercialized.

Because of the diversity of green businesses, with some more focused on reducing energy consumption and others more on improving environmental quality, there is great variation in the types of products innovated. In total, 154 businesses responded to an open-ended question asking for a description of their new product. Table 3 provides examples of new green products.

The most common process innovation had to do with *reducing resource consumption*. This includes reducing energy and water use, managing storm water runoff, and reducing waste. Businesses mentioned strategies ranging from installing solar panels to installing energy curtains to recycling water. The second most common strategy is the *use of greener materials and energy*. A small share of businesses, mostly green, also identified *reducing travel and using cleaner transportation methods* as a third, important strategy.

Almost half of survey respondents reported innovating a green product or service, as shown in Table 4. This in part reflects the survey sample selection process, which was heavily

Table 2. Top 10 Metropolitan Regions, Ranked by Green/Cleantech Innovation 2000-2008

Metropolitan Statistical Area Name	Patent Activity, 2000-2008		Venture Capital (VC) Investments 2000-2008		SBIR/STTR Grants, 2000-2008		Green Start-Ups, 2000-2007		Green Gazelles, 2008		Ranking	
	Cleantech	Percentage of State Cleantech	Cleantech VC Funds (in million $)	Percentage of Cleantech VC	Cleantech Grants (in million $)	Percentage of State Cleantech	Total Green Start-Ups	Percentage of State Green Start-ups	Green Gazelles	Percentage of State Green Gazelles	Overall	Cleantech
Los Angeles county	280	26.6	404	15.0	15.5	33.2	1876	25.9	774	21.2	2	1
Silicon Valley	245	23.2	827	30.7	5.2	11.0	315	4.4	168	4.6	1	2
East Bay	211	20.0	441	16.4	1.5	3.2	605	8.4	415	11.4	6	3
San Diego county	97	9.2	130	4.8	8.3	17.8	622	8.6	330	9.0	3	4
Orange county	66	6.3	154	5.7	6.1	12.9	667	9.2	394	10.8	5	5
San Francisco–San Mateo–Marin	48	4.6	433	16.1	1.3	2.8	416	5.8	203	5.6	4	6
Sacramento–Arden-Arcade–Roseville	30	2.8	7	0.3	0.6	1.3	500	6.9	259	7.1	8	7
Inland Empire	14	1.3	0	0.0	—	0.0	704	9.7	266	7.3	7	8
Santa Barbara–Santa Maria–Goleta	22	2.1	1	0.0	2.9	6.1	100	1.4	51	1.4	10	9
Oxnard–Thousand Oaks-Ventura	3	0.3	0	0.0	2.9	6.3	165	2.3	88	2.4	9	10

Source: U.S. Patent and Trademark Office; VentureXpert; U.S. Small Business Administration; NETS (National Establishment Time-Series). Calculations by the authors.
Note: SBIR = Small Business Innovation Research; STTR = Small Business Technology Transfer.
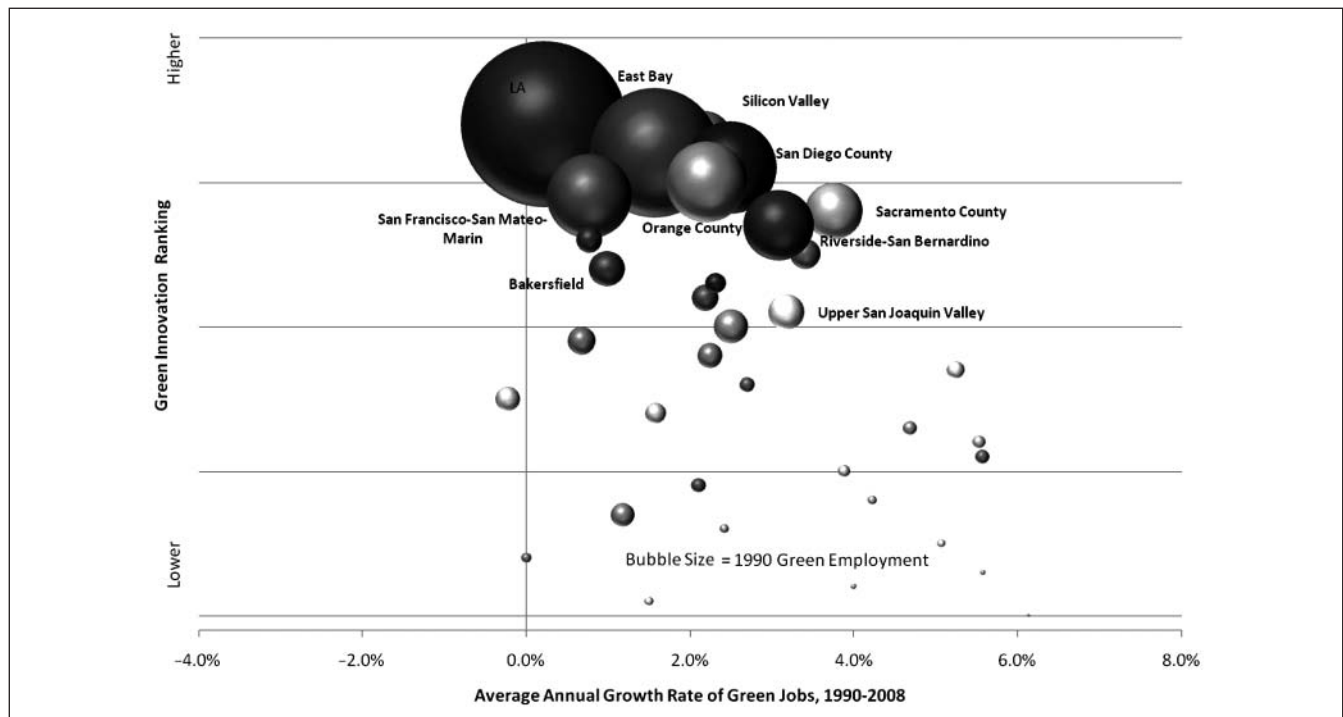
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Figure 7. Innovation versus growth in the green economy in California regions
Source: Calculations by the authors.

Table 3. Selected Examples of Product Innovation

Gas-to-energy facility
Absorbent pads and rolls made from recycled newspapers
Active power filter to reduce grid pollution and improve efficiency
Asset manager to help commercial office buildings reduce electric
  energy use
Service to help start-ups adopt green supply chain consulting practice
Columbia forest products
Compostable wine tray and bottle shippers
Cotton denim insulation
Deconstruction and salvage of remodeling debris
Designing zero energy houses
Direct photoelectrochemical hydrogen generation to derive hydrogen
Dual flush toilets, low-flow plumbing fixtures, recycled products,
  countertops
Geothermal reservoir engineering
Green alternative to particleboard, ChloroFill board
Greenhouse gas emissions measurement capabilities
Hybrid electric bicycles that encourage transportation alternatives
Improved solar still water purifier, improved solar-forced air heaters
Innovative wind blade design, soon to be in production
Installing native gardens to reduce water use and filter runoff
Instrument to measure refrigerant leaks for industrial
  refrigeration plants
Mix that uses recycled concrete as the aggregate
New calculators to help customers measure and reduce their carbon
  footprint
Solar-powered air-conditioning systems driven by a thermal system
Solar thermal combined with high-efficiency water heater, high-
  efficiency toilets

weighted toward green firms. Although 57% of green firms report introducing a new product or service, more than one third of traditional and more than 40% of TRI firms also innovate products or services.

The highest rates of product/services innovation is reported among architecture/engineering (e.g., introducing Leadership in Energy and Environmental Design [LEED] standards and sustainable design), construction (e.g., concrete recycling or pervious concrete products), and energy firms (e.g., introducing water reclamation methods). Firms with local markets are most likely to report innovating either new products or processes. In many cases, the innovation involves an adjustment to a local product or service to improve sustainability or reduce negative impacts, but new manufactured products include a wider variety (such as new measurement instruments and biodegradable products).

Introducing green processes is even more widespread among firms, with TRI businesses showing the highest rates of introduction (89% of firms). The high share of TRI companies implementing greener operational changes in their production processes (89% vs. 68% for green businesses) may indicate the impact of environmental regulations. Green companies, on the other hand, are more likely to have environmentally friendly production processes already in place and, hence, less need to change their processes. For instance, when talking about how environmental regulations have affected their business, a green building company located in Silicon Valley says, "Our 'green'

Table 4. Overview of Survey Responses

Question/Choices	Green Businesses (%)	Traditional Businesses (%)	Toxic Release Inventory Businesses (%)	Innovative Green Businesses (%)
Firm size				
<25 employees	70	61	14	70
100+ employees	14	16	61	11
Industry				
Construction	25	17	3	30
Manufacturing	10	22	82	14
Prof/bus services + utilities	46	16	0	43
Primary market type				
Private firms	41	51	64	35
Private households	42	27	13	53
Local government	9	5	4	5
Other public sector	9	16	19	6
Primary market location				
Within your city or county	47	42	17	59
Throughout California	18	16	21	12
Throughout the country	15	21	26	14
Throughout the world	19	20	38	13
Location of main competitor				
Within your city or county	56	57	22	63
Throughout California	16	11	12	13
Throughout the country	17	21	25	13
Throughout the world	11	11	17	12
Location of main external supplier				
Within your city or county	49	46	46	59
Throughout California	15	17	6	13
Throughout the country	20	21	35	13
Throughout the world	16	16	13	16
Location of main partner				
Within your city or county	62	59	45	69
Throughout California	12	7	5	9
Throughout the country	10	22	25	7
Throughout the world	16	12	25	15

direction was implemented and already set a higher goal than those regulations."

Innovative firms were distributed fairly evenly among regions, suggesting that geographic clustering of innovators may not be a crucial factor in the green innovative process. Of the regions of focus in the research, San Diego had the highest share of firms reporting product or service innovation, followed by Silicon Valley. The Inland Empire had the lowest share of firms reporting in product innovation, but the highest share of firms engaged in process innovation, followed by Silicon Valley.

Location, Industry, and Markets

Table 5 summarizes respondent characteristics and location responses that give insight on regional dependence. Size and industry characteristics vary significantly by respondent type. Green businesses are smaller than traditional or TRI business

and are much more likely to be in professional or business service industries. TRI firms are much larger than other firm types and are almost entirely manufacturing firms. These differences almost certainly influence many of the regional location considerations. The statistical analysis in the following section accounts for these differences.

Green firms and many traditional firms are in general locally oriented whereas TRI firms have a customer base extending nationally or worldwide. Innovating green firms are even more likely to be serving local private households. Green innovating firms also were most likely to face local competitors, to use local suppliers, and to interact with local partners.

Networks

Table 6 shows networking-related responses for the entire sample and for green product innovators, green process innovators, and

Table 5. Percentage of Respondents Who State They Innovate Products or Services or New Green Processes

Category (*n*: Respondents/Full Sample)	Innovate Green Product or Service (%)	Introduce Green Process (%)
All firms (*n* = 475/641)	49	69
Green firm sample (*n* = 272/358)	57	68
Traditional firm sample (*n* = 152/211)	36	64
Toxic Release Inventory firm sample (*n* = 51/72)	43	89
Architecture/engineering (*n* = 62/76)	61	69
Construction (*n* = 103/123)	59	79
Energy consulting/research (*n* = 28/37)	57	66
Environmental consulting/research (*n* = 57/78)	42	55
Manufacturing (*n* = 101/152)	50	70
Recycling (*n* = 20/25)	25	82
Transportation (*n* = 19/25)	37	70
Other industry (*n* = 84/121)	35	64
East Bay (*n* = 123/165)	46	58
Los Angeles (*n* = 99/129)	40	68
Inland Empire (*n* = 24/34)	36	88
San Diego (*n* = 60/77)	53	67
Silicon Valley (*n* = 68/85)	49	79
Upper San Joaquin Valley (*n* = 24/28)	46	67
Other (*n* = 66/82)	65	76
City/regional market (*n* = 200/213)	59	78
California market (*n* = 78/80)	37	68
U.S. market (*n* = 84/84)	49	60
World market (*n* = 90/92)	41	62

firms with growth expectations over the next 5 years. There is a wide variation in the degree to which different networks—defined based on frequency of interaction— are used. For example, the great majority of firms interact with similar businesses at least yearly, while less than half of respondents reported interacting with universities at least yearly. Firms that reported innovating either new products or services or new processes had more interactions than average with each of the networking categories shown in Table 6 (similar businesses, local government, universities, and nonprofits). Businesses expecting to grow, in contrast, were not more reliant in general on networks than other respondents, with the exception of slightly higher rates of networking with universities than the average respondent.

Statistical Tests of Innovation and Growth

The survey responses described above show considerable variation among the different categories of respondents. However, the source of these differences may not be attributable to the sectoral differences or experience with innovation. For example, green innovative businesses may be locally oriented because they are small businesses, rather than innovative

because they are small and locally oriented. We use probit analysis to statistically test the significance of specific location and network conditions in green innovation while taking other firm characteristics into account. The statistical equations are designed to test the significance of factors relevant to specific aspects of innovation theory, listed below.

We test three different types of equations—one for product innovation, one for introducing new processes, and one for growth expectations.

Equation (1) tests the probability that a firm reports innovating new products or services:

$$P(\text{Green Product Innovation} = 1) = \Phi(R, I, C, F, M, N), \quad (1)$$

where R = Region; I = Industry; C = Survey category (green, traditional, or TRI); F = Firm characteristics (stand-alone vs. branch or headquarters, full-time employment, establishment age); M = Market characteristics (primarily local/regional, primarily worldwide); N = Networking characteristics (contact with universities at least once a year; contact with nonprofits at least once a year). This equation tests several characteristics of green innovation.

On agglomeration and innovation, the equation tests whether innovating firms concentrate in specific geographic regions.

The equation tests the significance of local networks and resources in green innovation by looking at the relationship of university and nonprofit contacts to innovation as well as the importance of local or regional markets.

Industry and survey type, number of full-time employees, number of years in business, and establishment type (branch, headquarters, single location) are included to separate out different types of firm structure effects from agglomeration and networking effects.

Equation (2) tests the probability that a firm reports introducing new processes using the same explanatory variables.

$$\begin{aligned} P(\text{Green Process Innovation} = 1) \\ = \Phi(R, I, C, F, M, N) \end{aligned} \quad (2)$$

Equation (3) tests the probability that a business will expect to grow in the next 5 years, and specifically whether being an innovative business makes a firm more likely to grow.

$$\begin{aligned} P(\text{Grow in Next 5 years} = 1) \\ = \Phi(R, I, C, F, M, N, IN_1, IN_2) \end{aligned} \quad (3)$$

The model uses the explanatory variables described above, as well as two green innovation dummy variables (the product innovation and process innovation variables used as dependent variables in Equations 1 and 2). This is not a pure test of the relationship between innovation and job growth because it reflects respondents' expectations of future growth rather than actual change.

Table 6. Survey Responses to Frequency of Contacts With Selected Networks

Network/Frequency	Total No. of Responses to Question[a]	Percentage of all Responses	Product/ Service Innovators (%)	Process Innovators (%)	Expect Growth Over 5 Years (%)
Similar business in the region at least yearly	523	82	85	86	82
Similar business rarely or never	523	18	15	14	18
Local government at least yearly	510	69	75	76	69
Local government rarely or never	510	31	25	24	31
University at least yearly	492	48	56	52	51
University rarely or never	492	52	44	48	49
Nonprofit at least yearly	495	51	59	57	51
Nonprofit rarely or never	495	49	41	43	49

a. This is the maximum number who responded to the question on networks; some responses were lost in each column (product/service innovators, process innovators, and growth expectations) because some firms that answered the network questions did not answer the questions on innovation or growth expectations.

For each equation, several versions of the model are reported. The versions are described below in the context of the results.

Factors in new product or service innovation. Table 7 reports three versions of Equation (1), the probability that a firm will innovate a green product or service. Model I includes only regional and industry characteristics as well as dummy variables for firms drawn from the traditional or TRI samples. Model II adds firm and market characteristics, including establishment type, full-time employees, years in business, and a dummy variable for firms responding that the primary market area was local or regional. Because the type of firm may influence how market area and innovation interact, we create three different local/regional market dummies, one for each survey type (TRI list, traditional, or green). Model III adds two networking measures, establishments with weekly or monthly contacts with universities or those with weekly or monthly contacts with nonprofits, also separated into separate TRI, traditional, or green survey variables.

The model results are consistent with many of the descriptive statistics. Firms innovating green products do not appear to be concentrated in specific geographic areas of the state, controlling for other factors. Among industries, architecture/design/engineering, construction, and manufacturing each show significance across all three model versions for a positive relationship with innovation. (As mentioned earlier, many of the "innovating" architecture firms are introducing LEED into their building design.) The recycling industry has a negative and significant relationship with innovation in all three model versions. Not surprisingly, green establishments were more likely to innovate new green products and services than either TRI or traditional establishments, as shown by the consistently significant and negative estimated values in all three models for the TRI and traditional establishment dummies. Both green and traditional firms with local and regional primary markets were significantly more likely to innovate products or services

(as compared with firms with wider markets). This might be interpreted in different ways. It is possible that these firms obtain new ideas and initial demand from these local and regional markets. Or, this finding might reflect the fact that these more innovative firms produce products that are relatively early in the product cycle and thus have not reached the export phase. University networks were not significant for product innovation while nonprofit networks were significant only for traditional firms innovating green products, suggesting that outside support could provide the resources to allow a traditional operation to take advantage of new market opportunities.

We use the same set of explanatory variables in the model of introducing new green processes into a business. The results, shown in Table 8, indicate that different factors influence the introduction of new green processes than the innovation of new products or services.

Although the pseudo R^2 is slightly higher for this set of models, they clarify fewer tendencies because the significance of parameters is less consistent. Some regional differences are significant in this set of models. Silicon Valley firms are significantly more likely to introduce green processes than are firms in most other locations, for all three models. Inland Empire firms also showed significantly greater likelihood to introduce green processes in Models I and II. TRI firms are significantly more likely to introduce green processes than either green or traditional firms, in Models I and III. Older firms are more likely to introduce new processes; this could reflect either greater need to adopt new processes or greater resources for doing so. More locally oriented green firms are more likely to introduce new processes, as identified by local and regional market linkages and by use of nonprofit networks. This may indicate the use of innovative processes to improve competitive position in local markets.

Innovation and growth expectations. The models for Equation (3) differ slightly from the previous two sets. Models I and II are similar to those above, showing first regional,

Table 7. Probit Analysis, Probability That a Business Will Innovate a New Product or Service (Marginal Effects)

	I	II	III
East Bay	−0.034	−0.028	−0.080
Inland Empire	−0.145	−0.091	−0.120
San Diego	0.042	0.043	0.056
Silicon Valley	−0.017	−0.023	−0.100
Upper San Joaquin	0.083	0.109	0.132
Architecture/design/ engineering	0.154*	0.209**	0.205
Construction	0.146*	0.161*	0.161*
Energy research/utilities	0.179	0.225*	0.205
Environmental services	−0.102	−0.127	−0.092
Manufacturing	0.152*	0.240***	0.280***
Recycling	−0.262**	−0.284*	−0.260*
Transportation	0.023	0.077	0.038
Toxic Release Inventory (TRI) survey	−0.209**	−0.307***	−0.332**
Traditional survey	−0.258***	−0.327***	−0.374***
Stand-alone establishment		−0.139**	−0.098
Full-time employment		2.02 E-4	1.80 E-4
Years in business		0.001	−0.001
Local/regional market-TRI		0.010	0.092
Local/Regional market-traditional		0.252***	0.198*
Local/Regional market-green		0.176**	0.165**
University network-TRI			0.366
University network-traditional			0.030
University network-green			0.093
Nonprofit network-TRI			−0.092
Nonprofit network-traditional			0.279**
Nonprofit network-green			0.067
No. of observations	475	429	399
Probability value	.000	.000	.000
Pseudo R^2		.119	.150

*$p \le .10.$ **$p \le .05.$ ***$p \le .01.$

Table 8. Probit Analysis, Probability That a Business Will Introduce a New Process in Business Operations (Marginal Effects)

	I	II	III
East Bay	−0.092*	−0.055	−0.103
Inland Empire	0.184*	0.164*	0.136
San Diego	0.004	0.057	0.085
Silicon Valley	0.118*	0.116*	0.120*
Upper San Joaquin	−0.034	−0.028	−0.134
Architecture/design/ engineering	0.051	0.024	0.040
Construction	0.124*	0.038	0.083
Energy research/utilities	0.002	−0.096	−0.103
Environmental services	−0.108	−0.156	−0.075
Manufacturing	−0.077	−0.091	−0.038
Recycling	0.135	0.068*	0.108
Transportation	−0.006	0.033**	0.064
Toxic Release Inventory (TRI) survey	0.243***	0.141	0.236**
Traditional survey	−0.051	−0.100	0.004
Stand-alone establishment		0.024	0.065
Full-time employment		6.41 E-4	3.61E-4
Years in business		0.005***	0.007***
Local/regional market: TRI		−0.021	−0.196
Local/regional market: traditional		0.128*	0.118
Local/regional market: green		0.150***	0.134**
University network: TRI			−0.002
University network: traditional			0.086
University network: green			−0.385
Nonprofit network: traditional			0.077
Nonprofit network: green			0.175***
No. of observations	496	444	403
Probability value	.000	.000	.000
Pseudo R^2	.073	.136	.165

*$p \le .10.$ **$p \le .05.$ ***$p \le .01.$

industry, and sample variables and then adding firm and market characteristics. Model III adds the innovation measures, testing separately innovation by TRI, traditional, and green firms. Model IV adds the network measures (universities and nonprofits) for each survey type. Results are shown in Table 9.

Regional differences are not consistent among the four models, although East Bay firms appear less likely to expect to grow than firms in other parts of the state, with significant negative parameters in Models III and IV. There are strong differences among firm types. Construction, manufacturing, and transportation firms have significant, positive parameters

for all four versions of the model. Energy firms show a weaker positive expectation of growth. Traditional and TRI survey firms have negative relationships to growth expectations, but the results are significant inconsistently, and only in Models I and II. Stand-alone establishments are less likely to expect to grow, as are older firms. This latter finding is not unexpected because younger firms or firms just starting up are more likely to grow than are more well-established firms.

The strong negative significance of local/regional market orientation and expectations for growth among green firms seems perplexing given the importance of local and regional markets in both types of innovation. This result may hint at the weak relationship between regional innovation and job growth and indicate a barrier to expansion over the longer term. Green establishments appear to thrive within a local market in terms of innovating new products and introducing

Table 9. Probit Analysis, Probability That a Business Expects to Grow Over the Next 5 Years

	I	II	III	IV
East Bay	−0.020	−0.050	−0.092*	−0.139**
Inland Empire	0.095	0.090	0.060	0.024
San Diego	0.090*	0.052	0.005	−0.027
Silicon Valley	0.067	0.076	0.037	−0.033
Upper San Joaquin	0.078	0.082	0.0469	0.027
Architecture/design/engineering	−0.007	0.049	0.013	−0.027
Construction	0.105**	0.156***	0.129**	0.129**
Energy research/utilities	0.130*	0.136*	0.118	0.117*
Environmental services	0.062	−0.011	0.022	0.019
Manufacturing	0.120**	0.112**	0.115**	0.126**
Recycling	0.052	0.046	0.049	0.052
Transportation	0.116*	0.144**	0.149**	0.131*v
Toxic Release Inventory (TRI) survey	−0.095	−0.368***	−0.377	−0.373
Traditional survey	−0.093**	−0.235***	−0.169	−0.124
Stand-alone establishment		−0.123***	−0.121***	−0.097**
Full-time employment		−4.75 E-5	−4.64E-05	−4.87E-05
Years in business		−0.001	−0.002*	−0.003**
Local/regional market: TRI		−0.105	0.019	0.075
Local/regional market: traditional		−0.109	−0.084	−0.112
Local/regional market: green		−0.238***	−0.215***	−0.240***
Innovate product/service: TRI			−0.031	v0.215
Innovate product/service: traditional			0.098*	0.068
Innovate product/service: green			0.047	0.013
Innovate process: TRI			0.037	0.064*
Innovate process: traditional			−0.035	0.007
Innovate process: green			0.023	−0.024
University network: traditional				−0.038
University network-green				0.103*
Nonprofit network: TRI				−0.226
Nonprofit network-traditional				0.064
Nonprofit network: green				0.119**
Number of observations	550	410	386	353
Probability value	.001	.000	.000	.000
Pseudo R^2	.052	.148	.161	.229

*$p \le .10$. **$p \le .05$. ***$p \le .01$.

new processes, but may need ultimately to expand to wider market areas for long-term establishment growth. Green firms expecting to grow in the long term took advantage of both university and nonprofit networks.

The innovation variables showed only weak relationships to growth expectations and were significant only for traditional firms in terms of product innovation and for TRI firms in terms of process innovation. (For both these variables, where not significant, the estimates were still very close to significant at the 10% level). These findings could show that traditional firms that are innovating green products and TRI firms that incorporate green processes are more likely to expect to grow than their counterparts that are not taking part in the green revolution. Other economic factors may also be driving the weakness of the innovation variables results. For example, because the survey occurred in 2009 during a severe economic downturn,

establishments in industries such as construction and manufacturing may have seen no way to go but up, and thus answered that they expected to grow in the next 5 years, with or without innovation.

Conclusion

Patterns of innovation in the green economy show a role for regional innovation, but at the same time bring into question aspects of conventional wisdom about regional innovation systems. Our research is just a first step toward investigating how innovation in the green economy differs, suggesting areas for future study.

Whereas the aggregate statistics showed some concentration of resources of innovation, statistical analysis of individual firm behavior showed little regional influence. Type of industry

does matter, particularly for innovation of new products rather than processes. Unlike most regional innovation systems, the green innovation system is dominated more by local markets than universities. But the relationship between innovation and job growth is not straightforward: The innovative green firms most tied to local markets do not anticipate much employment growth, but green firms with university links more likely expect to grow.

Previous research has offered mixed results on the role of market structure in innovation. Like others, we do not find a clear relationship between firm size and the likelihood of innovation. However, the NETS data allow us to measure different firm characteristics, such as establishment age and whether it is part of a larger company. We find that older businesses are more likely to innovate in terms of green process, and stand-alone establishments are less likely to innovate new green products, raising questions about the role of start-ups in innovation. As use of the NETS becomes more common, future research on innovation should explore these findings further.

Our descriptive analysis finds that green innovation is highly concentrated in a handful of California regions, while green job growth is more dispersed. This clustering provides support for previous work on regional innovation systems and the association between innovation and localization economies. However, unlike information technology clusters, which take hold, at least initially, in highly specialized regions, green or clean technology clusters are emerging both in more diverse economies such as Los Angeles and more specialized nodes such as the East Bay. Thus, it is perhaps not surprising that our regression findings found little or no significance for regional dummies (except for process innovation in Silicon Valley and the Inland Empire). From an economic development point of view, it is encouraging that process innovation and growth may be widespread, even as product innovation is concentrated.

Innovation related to the green economy seems to occur within regional innovation systems, but not necessarily the university-centered regional innovation systems often depicted in the literature. In our models predicting innovation, the network variables did not necessarily have the anticipated positive effects. Nonprofit networks are important for traditional firms innovating green products and for green businesses innovating green processes, but networks with universities are not significant for innovative firms, only showing marginal significance for green firms expecting to grow. However, another form of network *does* seem to matter: embeddedness in local/regional markets, which plays a significant role for both green and traditional establishments. This suggests a new direction for the literature on regional innovation systems, which typically treats markets as an afterthought. More qualitative research could help to shed light on the role of local networks and markets, as well as competition between firms, which this research did not address.

The research indicates that the green economy is not easily defined within existing industrial categories. Green practices are not limited to green businesses but span the entire economy while green innovation happens in a wide variety of locations, industry types, and even in firms that are not specializing in green industrial sectors. Like other studies, this research found that process innovation prevails over product/service innovation across firm types, market types, sectors, and regions. This is particularly true of California's more peripheral regions, likely due to their concentration of traditional industries and need to comply with environmental regulations. New green processes, products, and ultimately new industries may emerge from the large traditional companies, from TRI list companies challenged by new regulations, and from the gazelles in small firms in emerging green industries.

Both the data descriptions earlier in the article and the statistical analyses of survey responses indicate that innovation in the green economy is not a guarantee of employment and income growth, although it can play a role for some firms. On the one hand, survey findings suggest that TRI establishments introducing green processes may have a brighter outlook for growth than equivalent firms that are not changing their operations. At the same time, green companies that innovate may need not just markets but also the resources of support networks to translate new ideas, products, and services into new business. Given that these findings are based on a survey taken in the midst of a recession that asked about growth expectations rather than actual change, more research is needed to understand this relationship better.

This research suggests that governments have many tools beyond traditional R&D strategies to help foster green innovation (and help grow the green economy as well), including regulations and standards, incentives, market-building approaches, and cluster strategies. But the appropriate tool kit will vary from region to region.

Local government matters to green innovation and to the green economy more generally; local climate action plans, building codes, financing schemes, and procurement can all help build a market for green products and processes. Thus, the more proactive local governments will likely emerge as the winners, at least initially, in the green economy.

The state remains the most important actor in promulgating cleantech innovation and green economy growth. State regulation helps level the playing field across California regions, encouraging green job growth through process innovation in locations such as the Inland Empire and Upper San Joaquin Valley. Still, the heavy hand of the state will not be uniformly popular, and some footloose firms may leave. To foster economic development within the state, California state policy will need to be proactive, providing incentives and alternative strategies that encourage energy conservation and the reuse of materials.

One of the characteristics of emerging new industries growth is that much new growth takes place at the "edges" of traditional industrial categories and across industries. The case of green

activities in California is consistent with this pattern and suggests a direction for economic development. In particular, it is the combination of the needs of TRI and traditional firms and the ideas and new directions of green firms that may lead to stronger economic activity. That green activities have permeated traditional and TRI firms as well as green businesses throughout the state points to California's role as a leader of green innovation and as a green regulator. This in turn suggests a need to reexamine empirically prevailing conceptions (such as that put forth by the U.S. Chamber of Commerce) about the incompatibility of environmental regulation and economic development.

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Notes

1. Adapted from Karen Chapple (2008).
2. For instance, whereas an 8-digit SIC (17110403) designates Solar Energy Contractors, the corresponding 6-digit NAICS (North American Industry Classification System) code is much broader, including all Plumbing, Heating, and Air-Conditioning Contractors. SIC code 36219909, Windmills, Electric Generating, corresponds to NAICS 335312, Motor and Generator Manufacturing. Thus it is difficult to use the NAICS system to identify the industries specifically engaged in activities that reduce energy consumption or improve environmental quality.
3. Some green products (e.g., organic food) could not be included because they have no 8-digit code.
4. We measure sales growth relative to other establishments within the same 3-digit SIC code in order to control for underlying trends in industrial restructuring (i.e., the long-term decline in manufacturing vs. steady growth of services). Without using this industry-specific growth measure, we would likely find most gazelles in a few rapidly growing industries. In this case, we would simply be measuring broader trends rather than the presences of firms that are outperforming their peers.
5. This occurred in part because of address inaccuracies in the sample and in part because e-mail addresses provided for the establishment did not necessarily go to the address selected for the survey.
6. For the purposes of this report, we used the 2003 U.S. Office of Management and Budget (OMB) core-based definition of Metropolitan areas with a few modifications. First, we defined the East Bay region as Alameda and Contra Costa counties (also known as the Oakland metropolitan area) and separated it from the remainder of the Bay Area (i.e., San Francisco–San Mateo–Marin). Second, we defined the Los Angeles region as just Los Angeles County, breaking out Orange County by itself. Third, we combined three smaller metros in the San Joaquin Valley (Merced, Stockton, and Modesto) to make a single region, which we call the Upper San Joaquin region.
7. However, it is important to note that our data only measure patents that are assigned, and would therefore not capture any recent spike in patent applications due to a typical lag more than 2 to 3 years for the U.S. Patent and Trademark Office to issue a patent.

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