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A model for disruptive technology forecasting in strategic regional economic development

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Abstract

As regions look to increase their economic development activities, technology-based developments and the penchant for long-term developments in disruptive technologies like nanotechnology become an important part of the options available to these regions. There are typically many technologies and therefore product areas that the region, however, can further develop by investing resources in these areas. At the same time, other regions in the world are considering the same areas of great growth and potential financial and social returns. This paper proposes a model that analyzes several important factors that can lead to success in analyzing these factors promoting the idea that policy makers should analyze the situation from different perspectives to reach justifiable decisions. These factors include the research capabilities of the region, its commercialization and manufacturing capabilities and the markets on which they should focus. Several mathematical models are then presented to help in that endeavor.

1. Introduction

As policy makers examine the future economic plans for their regions, they should consider the current state of the region, its capabilities in education, technological research, capitalization and infrastructure. This is especially true for emerging disruptive technologies such as nanotechnologies. These current conditions combine to provide the region with its forecasts of economic and social performance.

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Forecasting allows planners in technology and business to choose the right strategies for the future. Martino [1] suggests that it is as much planning for action as it is the planning to avoid costly mistakes of going down the wrong path. There are many methodologies from Delphi to statistical multivariate analysis that can be applied to many different forecasting situations. These forecasting methods apply to tasks as varied as estimating a small startup's potential number of users to the path that a region needs to adopt to bring technology-based jobs and wealth to that region. Martino [2] in a later effort includes environmental scanning through data mining as part of the new methods used given the advances in computer processing and data manipulation capabilities. Saren [3] uses a diagnosis of the technological capabilities to forecast the trajectory of a technology into the marketplace. However, this paper will explore how many of these have been applied to emerging disruptive technologies such as nano-technology, Microsystems and other potentially disruptive technology bases.

Porter et al. [4] focus on the competitive edge the technology gives a company or a region in pursuing its goals of advancing productivity and other economic agendas. To be able to harness this competitive edge, a manager needs to understand and deal with the uncertainty presented by a future that depends on many variables from technology capabilities to customer preferences to economic, political and cultural drivers. Forecasting is the key to this understanding. Twiss [5] suggests using hard data when possible for forecasting. Otherwise other methods such as scenario analysis or expert opinion should be used to allocate resources under uncertainty of future events. He maintains that forecasting does not negate the need for managing unexpected eventualities but to be prepared to understand the relationship between the different existing factors. Porter [6] indicates that with new information methodologies, one can search for relevant forecasting information in a quick and efficient manner. Devazas [7] shows that logistic equations predict the diffusion of technology and products into markets.

In today's economic climate, technology-based development plays a major part in every region's planning activities. Regions that are interested in maintaining and/or increasing its standard of living turn to technology to make this possible. Many [8,9] maintain that capitalist systems are concerned with two major imperatives: creating new jobs and developing the economy through structural changes of innovation and through productivity improvement. In both of these situations, technology plays a major role. To be able to utilize technology for regional economic development, a region needs to undertake a forecast of its capabilities in R&D, its relative competitive advantage in the areas where they excel, its commercialization and manufacturing expertise and the nature of the markets for the products that can be produced. These products are the result of utilizing the R&D, commercialization, manufacturing and market penetration capabilities of the region to bring jobs and create viable commercial enterprises in that region.

One of the areas where the creation of new jobs and structural changes to the economy occur is the use of disruptive technology in the creation of new small high-technology firms. Kassicieh, Walsh, Kirchhoff and McWhorter [10] examined the role of small firms in technology transfer in disruptive technologies. Birch [11] and Kirchhoff [12] proved the importance of small firms in entrepreneurship and job creation. Kirchhoff, Kassicieh and Walsh [13] highlighted the importance of disruptive technologies to firm creation and Kassicieh et al. [14] showed the importance of small firms in the technology transfer of disruptive Microsystems and nanotechnology discoveries to commercial endeavors.

In this paper we will present a model of analysis that helps regions in analyzing these capabilities and in reaching conclusions on where they should proceed in their economic development based on forecasting and business analysis techniques. In Section 2, we will identify the areas in which the region has its major R&D capabilities and analyze the comparative competitive advantages that these capabilities give to the region for industrial development. We use the state of New Mexico as an example. In Section 3, we will examine some of the economic environment variables of the region. These include:

1. R&D in the region
2. Entrepreneurship
3. Entrepreneurial support: incubators, support organizations, existence of cluster base companies
4. Tax and incentive structures in the region
5. Infrastructure: such as transportation, telecommunications, water, power and logistical support
6. Capital: venture, angel and other forms of investment capital
7. Educational institutions at secondary, 4-year and graduate college levels
8. Quality of life issues.

These areas help the region in attracting, enhancing and creating new companies that will support its economic development initiatives.

In Section 4, we examine markets for the industries that coincide with the R&D capabilities and that are supported by these economic variables. In Section 5, we design a model that allows us to evaluate the information collected and use it to make decisions in the region. Section 6 covers further research and conclusions.

2. R&D capabilities

Many authors support the view that R&D is essential for economic development (Coccia [15], Sorensen [16] and Suarez-Villa [17]). Colgan and Baker [18] studied clusters based on technological innovation. They maintain that these clusters have become the central piece of many economic development regional plans but that these clusters do not have major economic impact but present regions with the potential for future growth. Chew and Chew [19] present the case of Singapore where R&D needs to be encouraged so that the entrepreneurial class can take the economy to the next level. Marceau [20] suggests that an R&D agenda that is industry-focused with all of the industry players rather than a select few is more effective in stimulating innovation and growth rather than a national approach with few players.

For a region to forecast the area in which it should focus its resources and develop clusters of companies in the same industry, R&D analysis is a must. In this vein, the ability to view a regions' R&D portfolio in a single interactive visualization is a powerful notion. The visualization will allow insight into the patterns, trends, and relationships embedded within the portfolio. On a macro scale, landscape visualizations (built by applying clustering algorithms across a document set) can expose technologies that form a critical mass amongst multiple institutions. On a micro scale, landscape visualization can expose each individual institutions R&D portfolios. This capability on both a macro and micro scale allows institutions to understand and leverage each others technological capabilities. We will examine New Mexico's 1991–2004 patent and scientific journal portfolio in Figs. 1 and 2. The proposed activities are as follows:

2.1. Step 1: examine patents in particular areas which have been identified as ones where the region could have a competitive advantage

New Mexico's patent portfolio depicted in Fig. 1 consists of all institutions and business that have either a patent or patent application granted between 1999 and 2004. However, a majority of the patents in

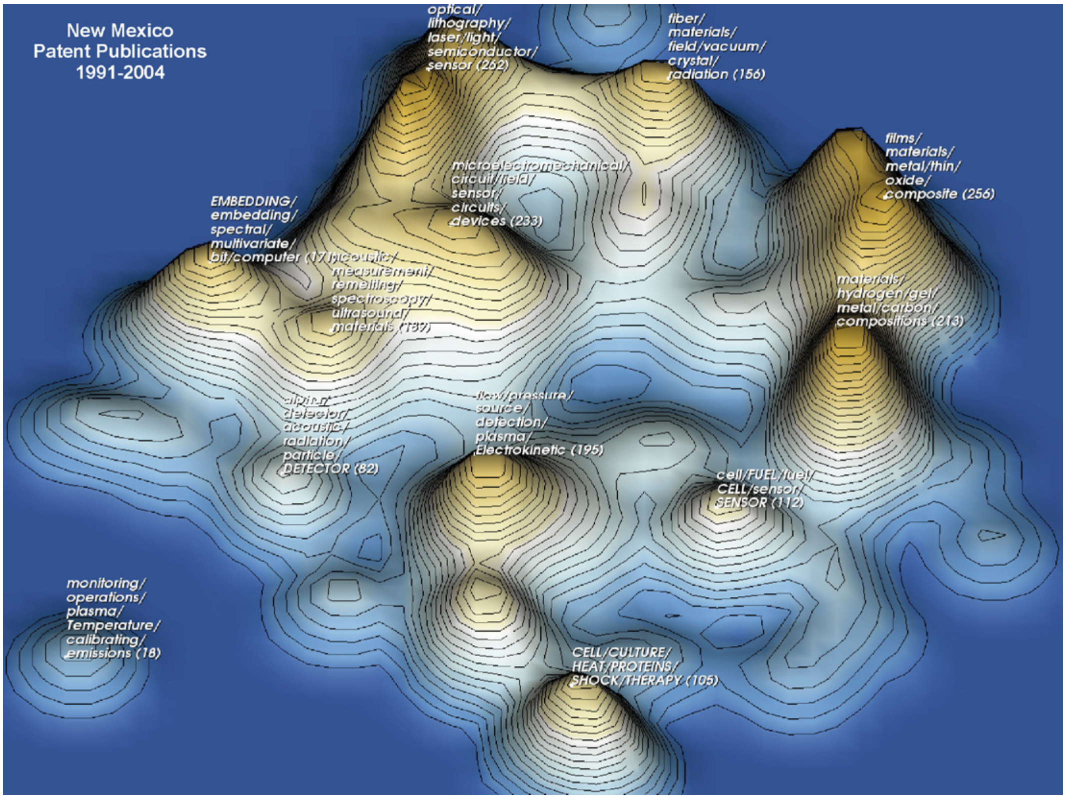

Fig. 1. Graphical representation of patents in NM from 1991–2004.

New Mexico's portfolio originate from Sandia National Laboratories, Los Alamos National Laboratories, University of New Mexico, New Mexico State University, and New Mexico Tech.

At a quick glace it is easy to get a sense of what technology areas New Mexico possesses. The distribution of technologies ranges from laser and optics, micro and nanoelectromechanical fabrication, chemical sensors, superconducting materials, radiation detection, micro and nanofluidics, and fuel cells. As depicted in Fig. 1, the prominent technology in New Mexico's portfolio is laser and optics.

Although there is now an understanding of what New Mexico's patent portfolio looks like, it would also be valuable to identify each institutions patent portfolio. This can be accomplished by simply querying on each institution of interest, which will result in dots emerging on the landscape with unique color codes. The value of this type of analysis consists of the ability to identify technology areas that two or more institutions may be operating in simultaneously. As a result, the institutions may partner to leverage their capabilities.

A caveat to the approach of analyzing New Mexico's technology portfolio based just on patents exists. Most of New Mexico's patents come from government institutions. As a result, there is a limited patent budget which equates to an incomplete view of New Mexico's technological capabilities. In order to gain a complete perspective, it is imperative that a similar assessment of scientific journals be conducted.

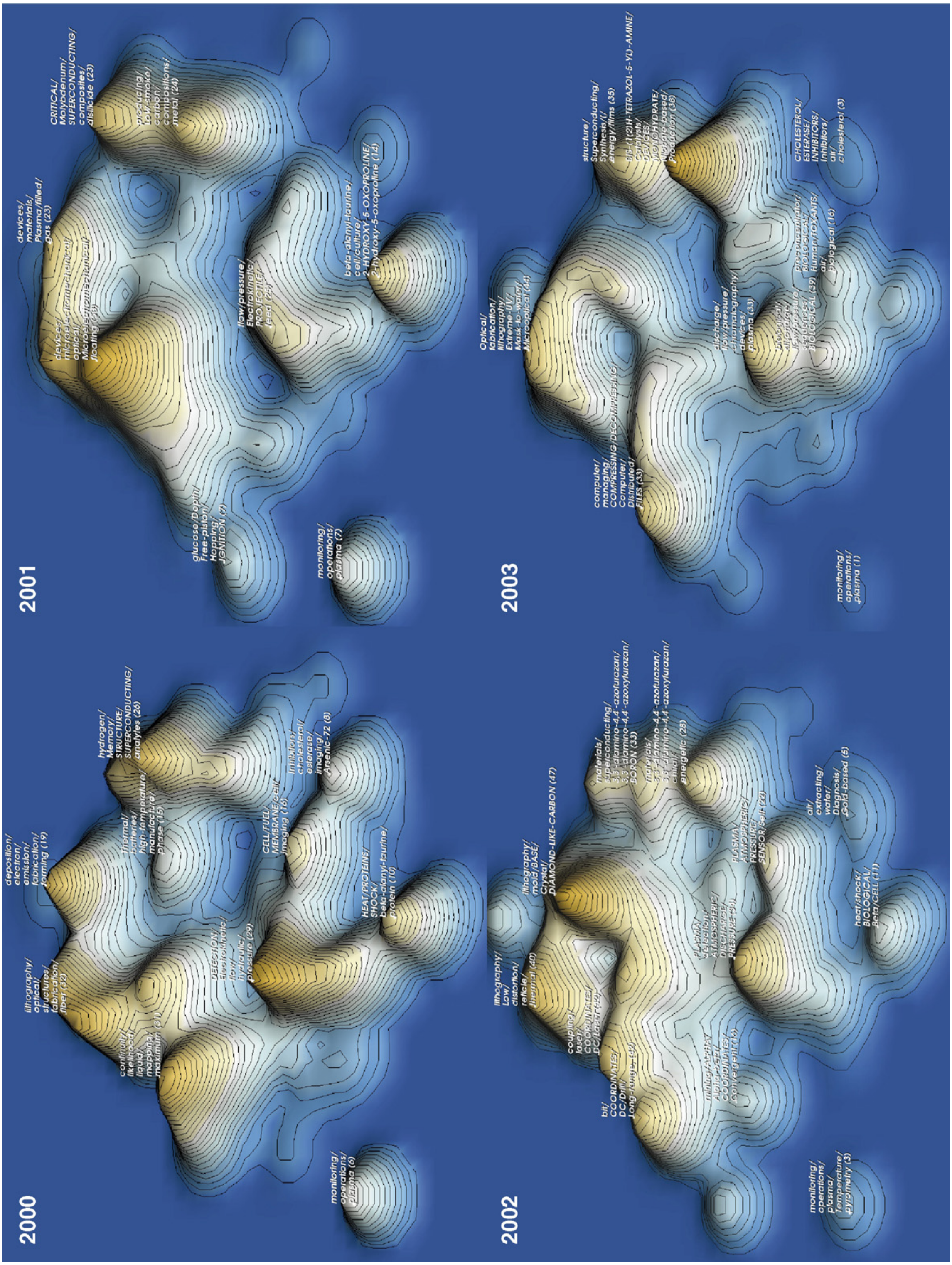

Fig. 2. Scientific publications from NM 1991–2004.

2.2. Step 2: examine publications from the major R&D institutions of the region

The development of a landscape visualization for New Mexico based on scientific journals reveal both hidden technology not represent in the patent domain as well as underlying technological knowledge and capabilities that can be used to forecast technological progress.

Consistent with New Mexico's prominent patent technology (lasers and optics), the scientific journal assessment depicts thin films, microstructures, and lasers as the top two technology areas. Once we have identified the areas in which the region is competitive, we use the secondary literature to identify other areas of the world that can compete with the region in terms of R&D in these same areas. The same procedures are then used to analyze the competitor regions from an R&D standpoint using the two steps defined above.

The technique of applying landscape visualizations to identify technology portfolios can be used to forecast regional technological research and development. Forecasting is possible through applying a temporal filter to the landscape visualization so that time slices of past technological domains can be viewed through an animation. Fig. 3 depicts a four year trend analysis of New Mexico patents and Fig. 4 depicts a four year trend analysis of New Mexico journals. The trend analysis effectively identifies portfolio elements that portray longevity and elements that portray quickly emerging technologies. However, in technologies such as Microsystems, a distinct technological roadmap emerges. For example, in the 2000 patent portfolio,

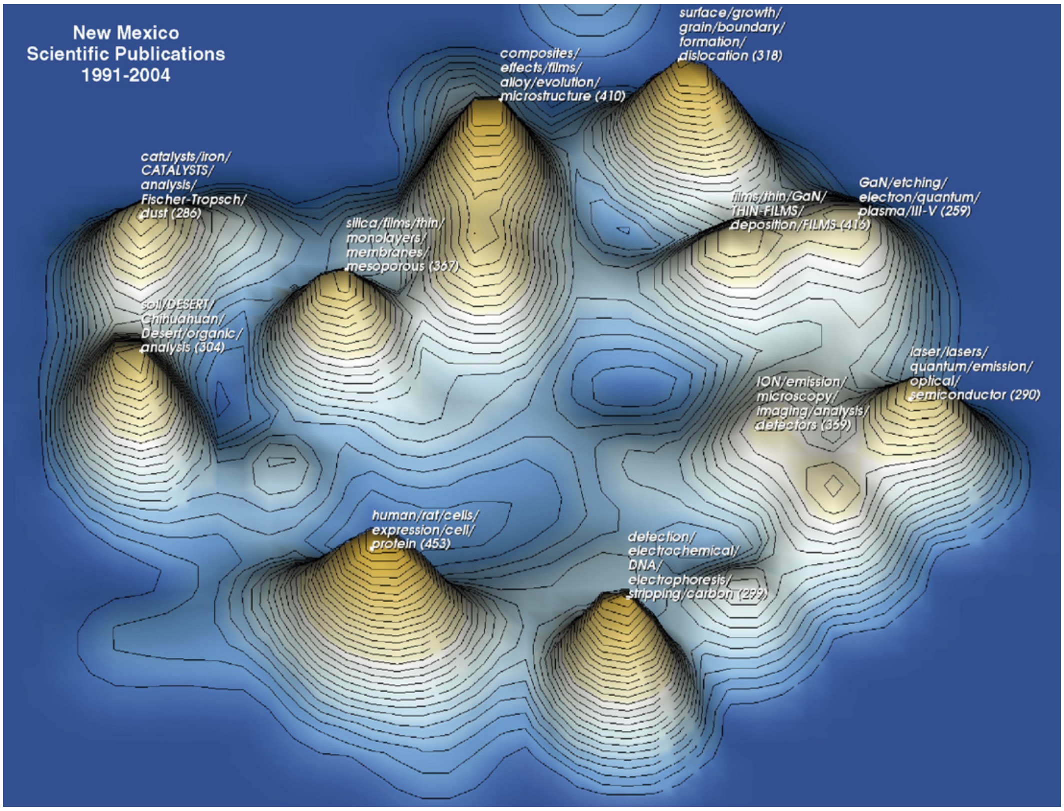

Fig. 3. Patent publications from NM 2000–2003.

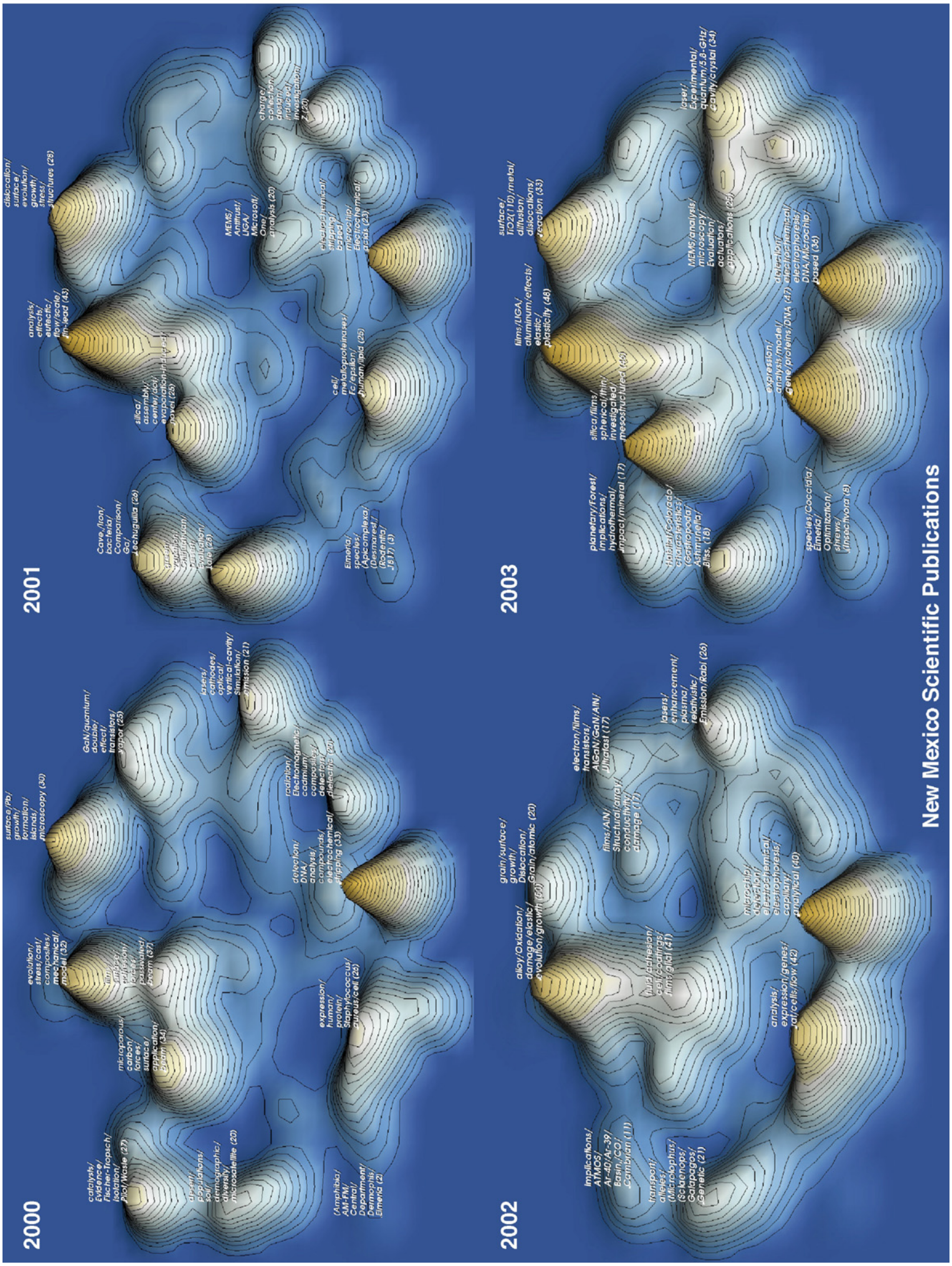

Fig. 4. Scientific publications from NM 2000–2003.

materials, lithography, and fabrication technologies were prominent. In 2001 and 2002, MEMS components and advanced lithography technologies emerged as prominent. In 2003, specific components such as MEMS biological devices start to surface. By identifying, visualizing, and understanding technology portfolio trends, predicting future direction is more conceivable.

Although the visual analysis of technology portfolios are valuable in determining what technological strengths exist within a region, determining the commercialization prospects cannot be achieved by this method alone. As a result, it is imperative to include in the dataset a list of companies that have received venture funding in the past five years. Examples of New Mexico startups and their associated technologies include power-on-a-chip applications, biometric sensor products, computer-aided engineering platforms, micro-powder composition technology for semiconductor packaging, genomic markers that predict disease progression, remote monitoring solutions, photovoltaic cells, noninvasive diabetes screening, and noninvasive alcohol monitoring and screening systems. These technologies turn out to have a strong correlation to the dense journal and patent portfolio cluster depicted in Figs. 1 and 2. With the addition of “company start-up” data, there essentially exists a technology life cycle consisting of research (scientific journals), development and application (patents), and commercialization (Venture Capital supported Start-ups).

2.3. Step 3: examine the competitive position of the region versus other regions in the top few technology research capabilities

Citation analysis is a method where one region’s competitive position can be compared to another within a similar technology domain. In regard to scientific journals, it is generally accepted that journals that have been cited more, often translate to a strong base of knowledge and/or innovation for the corresponding author and institution. In regard to patents, it is generally accepted that the more times a patent is cited the more “commercially valuable” it is (that is when it is standardized across time and industry). Applying either or both of these metrics allow for the comparison of multiple regions in determining which one has a stronger competitive positioning in regards to a supporting research and development environment.

3. Commercialization capabilities

The technology and economic development literature examines many factors that help regions in establishing new firms, growing the existing ones and/or recruiting successful ones. Each one of these activities requires a different type of effort. In recent past development economics was more concerned about the superiority of market economies over government controlled initiatives and was not focused on the causes of poverty and problems of underdeveloped regions [21] but now issues such as economic and social issues are studied.

These factors are:

1) *Entrepreneurship*: DeGregori [22] argues that technology transfer remains the main driver of economic development. Shanklin and Ryans [23] maintain that an economy has to attract new companies, enhance existing ones and create new startups to engage in entrepreneurial activities that lead to economic development. Venkataraman [24] indicates that the prerequisites to

technopreneurship involve many factors above and beyond risk capital such as R&D and innovation, region-specific opportunities and access to large markets. Phan and Foo [25] indicate that governments have realized that technology is a major driver of economic growth and has thus tried to create the appropriate atmosphere in many areas such as education, quality of life and capital availability to create new technology firms.

From this perspective it is imperative for the forecasting team to establish a sense of the people that can lead activities in this technology/product area in the region from multiple perspectives:

1) Estimate the number of entrepreneurs in the area that have the potential to start businesses in the same space. This number could be determined by looking at the membership in organizations that support the cluster of technology or by economic development support groups with knowledge of people that have been examining this potential.
2) Determine the number of existing businesses in the product space. These are firms that are looking for opportunities to enhance or upgrade their skills and capabilities in this area.
3) Forecast the number of firms that can be attracted to the region to work in this product area. Attraction depends on many factors such as quality of life, tax incentives, support for business, water, work force, financial resources and education among others.

2) *Support organizations*: one of the important determinants of entrepreneurial activity in a region is the situation or environment which supports the entrepreneurial activities. Martin [26] and Louis, Blumenthal, Gluck and Stoto [27] and Shefsky [28] found that supportive environments produce more entrepreneurial actions by technologists. Wright, Birley, Mosey [29] indicates that university policies and internal environments affect the rates of spin-out ventures. Degroof and Roberts [30] indicate that policies are essential to the incidence of entrepreneurship from university faculty. Miller [31] indicates that entrepreneurs have a higher chance of succeeding in supportive clusters than in locations that do not support their activities.

The forecasting team needs to examine the list of support organizations and what they do to help firms in their startup, enhancement and/or relocation activities.

3) *Tax structure and Governmental incentives*: Von Bargen et al. [32] indicate that tax codes and other governmental policies affect the rise of entrepreneurship. In order for a region to be supportive of new firm creation, three areas should be considered: a) the current tax burden in the location, b) the availability of tax incentives to firms in this area and the criteria for qualification and c) potential pending legislation by the state for new tax incentives. These could be specific to the technology area but also could be general for work force training, manufacturing tax credit or research tax credit and/or many of the other types of incentives.

4) *Infrastructure*: Neck et al. [33] indicate that in their examination of success factors of entrepreneurial startups, they found that the presence of infrastructure and social networks contributed positively to new technology firms in a region. For a region to succeed, sufficient existing infrastructure supporting the transportation, telecommunications, electric and water needs of the firms in a particular industry or technology area should be present. Depending on the type of industry, the requirements for railroad, air or highway access to bring in raw materials or to ship intermediate or final product is essential and can be a contributor to the final market price of the products of the industry. In the same fashion, the water or power (electric, gas or other forms) that are available and the existing conduit can also have an impact of the cost that accrues to the production facilities. Telecommunication capabilities are essential these days for supply chain and customer relationship management that it will be hard for any company to locate in an area where

high speed connectivity is not available in the region and in many situations where the "last mile" problem has been solved for these facilities. One of the issues here is the water resources and this can have social and economic implications to the region far beyond the availability for a certain development process. That has implications for this analysis and how it is perceived by the parties that might be affected by a higher than normal need for this resource.

5) *Capital*: Wonglimpiyarat [34] indicates that the success of Silicon Valley was driven by a few factors such as the ones listed above as well as the abundance of venture capital. Auken [35] proposes that the availability of venture capital supports regions in their economic development efforts. The availability of angel, venture and debt capital that can support the creation of industrial facilities is important to gauge as a region undertakes an examination of its capabilities. The requirements for the return and risk ratios are higher when one has to look for capital outside of the region.
6) *Education*: Kuruvilla et al. [36] indicate that the development of high skills support the economic development of a region and use the Singapore model as an example. Gottlieb and Fogarty [37] review the link between educational attainment at the bachelor's level and economic growth. Goetz and Rupasingha [38] report that states are interested in more university graduates as a way to increase economic growth. Feller [39] indicates that support for technological education is increasing while support for general education is being curtailed and that this trend produces a vicious cycle where deterioration in economic terms will result.

   This is important for many different reasons:
   1) General level of education of the workforce: the more educated the workforce the more able they are to deal with the requirements of high technology-based manufacturing and the systems required to accomplish these tasks.
   2) Specialized skilled labor: this helps new high tech industries in having a supply of local labor that can be hired to accomplish the necessary tasks. Bringing talent from the outside begs the question about locating facilities away from the labor pools necessary for its success.
   3) University level education: this is important for managerial and professional talent required to accomplish the job. The availability of engineers and managers is important for the success of the endeavor.
   4) University or research institution R&D: continuous improvement to technology is a necessary survival requirement and facilities with a good source of new ideas fare better in the long term. Smilor and Matthews [40] indicate that the top universities that support technology transfer have contributed to the success of economic development in their regions.
7) *Quality of life and social networks*: Florida, Cushing and Gates [41] examine the importance of social networks and societies that encourage open communications in the success of economic development in regions. The willingness of the social networks to accept "new blood" and to support new initiatives is essential for success. The quality of life component is typically related to the social networks issue but can also be a major factor in attracting new industry to a region.

Each one of these issues affects the region and affects the ability of firms to attract, enhance and/or create new firms in the cluster technology areas or in general. The task that is important for the assessment of a region's economic development potential.

Other issues that are worth examining are the manufacturing support and capabilities that exist including the cluster effect of existing companies that can be suppliers or customers to new companies in the same industrial space. General support for business, exports, training and other business functions is also worth assessing.

4. Market analysis

This area of the analysis follows the typical market forecasts that have been covered by many authors such as Martino [1], Twiss [5] and Porter et al. [4]. The examination of markets and potential customers can follow mathematical formulations such as regression or models or expert opinion and Delphi methods. The only problem with some of these areas is that in some situations, the technology might be discontinuous and the products disruptive and newer techniques might be necessary to examine. Organizations that specialize in analyzing market in areas such as Microsystems or nanotechnology have been working hard on some of these issues and the economic development assessment team can get a specialized group to examine these areas if the traditional methods of forecasting do not apply.

The other part of the analysis of markets is to understand the competing regions and their capabilities. Instead of looking at the region's capabilities only, one has to look at other regions and examine as one did in the R&D capabilities analysis the comparative advantage that different regions might have in this area.

In analyzing markets, the lists of existing companies in the region and their products as well as their projected new offerings have to be taken into consideration. As an example, let us use New Mexico and look at its Microsystems market potential. The R&D at Sandia National Laboratories is world class and the University of New Mexico has several researchers that collaborate with Sandia and work with other groups around the globe on this issue. The competition however is fierce from states such as California with Lawrence Livermore, University of California at Irvine, Berkeley, Los Angeles and many companies in the area. Small Times magazine reporter Candace Stuart [42] ranked the states and their endeavors in Microsystems and California ranked at the top with Massachusetts, New Mexico, New York and Texas making the rest of the top 5. The rankings were based on research, industry, innovation, venture capital, workforce and costs. New Mexico scored well on all areas but lags quite a bit behind leaders California and Massachusetts. Competitors to New Mexico's Microsystems R&D, industry and other efforts include many companies, corporations, institutions, universities, or national labs that are conducting the same or similar research as New Mexico companies. These competitors have won government contracts, earned funding, or won grants for the R&D in Microsystems. The next step is to examine the existing companies in NM that are commercializing Microsystems. The list includes companies such as MEMX, Intellite, Surfect, Nanopore. The analysis then should turn to examining how these companies are positioned to create a cluster that could help the creation of suppliers or customers and therefore create an economic development set of activities.

The market analysis requires the examination of the literature and reports published by many of the market analysis firms that track the market for Microsystems. The market projections by group such as MANCEF (www.mancef.org) [43] or Nexus (www.nexus\-mems.com) or In-Stat (www.instat.com) should now be matched with the R&D capabilities and the existing companies to determine how well NM stacks in the projected areas. This analysis needs to examine the market for existing products but also the future projections for needs into areas that are feasible technologically but has not been fully exploited in the marketplace. Take for instance, the ability of Microsystems or nanosystems to detect biological and/or chemical hazards. If the region has capabilities in this area from a research standpoint and has many small startups in the area but the market is currently small but projected to be large, then this is a better situation for the region that a small market projection or a situation where the region cannot compete in this technology/product area. These analyses allow us to compare our capabilities with regions based on these analyses and to recommend a pathway for future endeavors.

5. A model for regional economic development in disruptive technology

In order for a region to decide to invest in a certain disruptive technology or to decide among different technologies, the region must analyze several factors. In this example we use the state of New Mexico and its quest for economic development in terms of company attraction, startup company creation [44], workforce development and other activities that support the idea of clusters in certain technology and/or product areas. The state has major R&D activities in three areas: Microsystems and related nanotechnology, hydrogen as a source of fuel and drug discovery based on genomics. These capabilities are based on the R&D organizations that are world class in these areas: Sandia National Laboratories in Microsystems, Los Alamos National Laboratory in hydrogen and the University of New Mexico Medical School and the Center for Genome Research among others in drug discovery. For New Mexico to decide which area it should follow, several steps outlined in this paper should be followed:

1) *Perform R&D capabilities analysis*: this can help identify areas where the region is ahead or areas in which it can be competitive given more investment. In NM, all three areas have strong research presence but the competition in hydrogen and drug discovery is high given the importance of hydrogen as an alternative to oil in energy needs and the large number of major medical centers that are working on genomics, DNA and other avenues to discover diagnostic, therapeutic and genetic solutions to many ailments. Combinations of areas such the use of Microsystems and nanotechnology in therapeutics or hydrogen fuel cells are possible and seem to be the sweet spot if the research areas and research direction could be combined.
2) *Analyze current and future markets*: as shown in Section 4 an analysis of the market both currently but more importantly, in the future should be performed using projections from special marketing groups that specialize in these market or product areas. Part of the difficulty here is the same issue with all disruptive technology, namely the projections depend on the movement of the technology to products and the market adoption rates for these new products. The Microsystems range of products from biomedical devices to telecommunications switches to sensors and many other makes it impossible to focus on the wide range and requires the regions to specialize in an industry such as telecommunications for success. In hydrogen, the need for infrastructure such as storage and supply links that need to blanket the nation or the world to be successful in delivering hydrogen as a source of energy replacing oil products is extremely expensive. Drug discovery is a long process that requires large amounts of investments due to the length of time it takes to get approval for new diagnostics tools or therapies. This is the area in which most regions struggle but to succeed they have to take the calculated risk after analysis in one of these areas. Otherwise they are left behind in the economic development game.
3) *Analyze the supporting infrastructure*: Many [45] suggest that the analysis should include all of the areas that can support the development of the industry based on the products of the technologies analyzed in 1 and 2 above. These include the supporting organizations from education and business groups, incentives for new or existing companies, logistics as in transportation, communications links as in telecommunications, venture capital and other capital availability for growth, quality of life for the retention of existing workforce and attraction of new participants. There are a lot of magazines that rank areas for many dimensions such as these and other (see for instance Forbes or Kiplinger reports, etc).The model is built by examining the factors listed above

and comparing the different technology/product options that are to be evaluated. For instance, let us examine NM's examination of its relative options related to three candidate technologies such as Microsystems, hydrogen and biotherapeutics/drug discovery. The values filled into each one of the cells of the model reflect the comparative position vis-à-vis international competition in these technologies. The model is expressed as follows with rankings of 1 (low) and 10 (high) in each category:

Technology			
Factors	Microsystems/nanosystems	Hydrogen	Biotherapeutics
Research/patents	10	9	8
Research/citations	7	7	7
Entrepreneurship	4	2	3
Support organizations	6	4	5
Tax structure and incentives	3	3	3
Infrastructure	4	2	3
Capital	7	5	6
Education	4	4	4
Quality of life and social networks	8	8	8
Total	53	44	47

The model uses a simple additive structure to determine the first rankings of the areas in which NM should engage and identifies areas that might need strengthening over time to make sure that the implementation of this technology is successful. We recognize that the world is changing competitively [46]. Obviously one can use more complex models that examine these issues in more detail.

6. Conclusions and further research

In this paper, we have tried to outline issues that are essential for policy and decision makers in economic development to examine options using some clear methods and facts that are analyzed to fit the goals of the region given its limited resources and potential future benefits. More work is needed to make the models shown here more robust and include other factors that are deemed important for economic development.

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