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Everything about genes: Some results on the dynamics of genomics research

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In this study some novel indicators and publication data resources are explored to study the dynamics of genomics research at three different levels: worldwide; national and at individual Research Centers. Our results indicate that the growth of genomics research worldwide seems to be stabilizing, whereas genomics research in the Netherlands aims at getting 'ready for the next step'. As we find differences in research dynamics at the level of individual Research Centers, governmental support in a 'next step' could take these differences into account. For this purpose, we introduce a general model of research dynamics and timing of research management, building on ideas of Price and Bonaccorsi. Based on this model a framework is presented to discuss steering options in relation to research dynamics. We apply this framework to Research Centers of the Netherlands Genomics Initiative (NGI) and discuss findings.

Introduction: Genomics research dynamics explored by using bibliometric indicators

In 2001 the Dutch Government established the National Genomics Initiative (NGI) to promote collaboration in the scattered genomics research activities in the Netherlands. The NGI's strategic plan for the period 2008–2012, aims at adding another € 300 million to the national genomics research infrastructure, to emphasize social and economic returns, and further strengthen the knowledge base in research, technology and education [NGI, 2006]. This 'next step' includes strengthening subfields as proteomics and bioinformatics (or: e-bioscience) and creating platforms for new subfields as metabolomics and ecogenomics.

In our research we try to provide (bibliometric) research information that helps enhancing the interplay of research dynamics and research policy. Besides calculating research indicators, we propose a model of research dynamics and timing of research management. This model may serve as a tool for policy makers and research management to follow the dynamics of research over time, and to better discuss options for timing and matching of steering interventions in relation to the internal dynamics of scientific research.

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Our first main question is how Dutch research fits into the dynamics of Genomics worldwide, and what differences, if any, can be found in the dynamics of the several centers and platforms related to the national genomics initiative. Is the genomics research field worldwide expanding, or stabilizing, and in what ways, and what can be said about our national research efforts in this respect? Our second main question is how NGI's steering measures will best fit the 'next step' in the dynamic development of genomics research in the Netherlands.

We looked at the presence of genomics research on the Internet, in the Web of Science and in a digital library repository, for the period 1990–2006, to get a rough picture of the dynamic development of the field of genomics and its subfields worldwide. Next, we looked at Dutch research contributions in the research output found in the Web of Science. Then we looked at output growth, research focus and collaboration in the research centers and platforms, to get an impression of the dynamics of Dutch genomics research as promoted by NGI. Finally we visited the Genomics Momentum by NGI [2006] to get an impression of the NGI atmosphere.

The results are set in a model of science dynamics and management (inspired by BONACCORSI [2005]) that looks at science as a creative process of knowledge construction, with alternating periods of diverging and converging research strategies (Figure 1). In this process, we distinguish two main dimensions. One dimension includes the contents of research fields, with differing richness to be explored that are approached and interpreted by researchers. BONACCORSI [2005A] denotes this dimension as a 'search space', or even 'search regime': the pattern of existing theories, hypotheses, objects and techniques, that scientists will follow in their search for solutions to particular scientific problems. Research in this dimension is characterized as '*convergent* if each conclusion adds to a more general one', or as '*divergent* if each conclusion gives origin to many sub-hypotheses and new (re)search programs'. We add to this, that in the course of time within a research field or program the search process may alter from a divergent to a convergent regime, or vice versa, depending on novel content produced. The way scientists proceed herein; we here call their 'research strategy' (Figure 1).

According to WHITLEY [2000], the autonomy of researchers over their research strategies is limited by the need to convince specialist colleagues (or peers) of the significance of their work. Though the level of this restriction differs between scientific fields, alternation of diverging and converging search periods may still occur well within the bounds of each field. The other dimension relates to the institutional settings of research rather then to its contents. It includes the prevailing institutional arrangements, organizational settings and strategies that are superimposed on research and researchers by research organizations, by government or business firms that take an interest in steering and harvesting science results. Steering initiatives, and policy measures within this dimension may influence the research strategies of groups, in addition to the prevailing search regime.

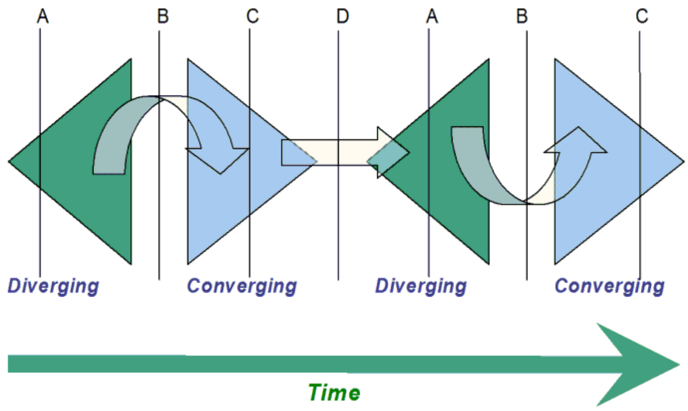

Figure 1. Alternating search regimes and/or research strategies

As to the first dimension, an indication of a search regime may be found in both research input, such as growth and diversity of research personnel and collaborations, and output, such as publication growth and diversity of topics chosen, as reflected in use of keywords [BONACCORSI, 2005A, 2005B], or in the scope of journals groups publish their work in, as we do here.

Looking at the second dimension, a main aspect of concern is how policy steering measures fit the development of the research (Figure 1 A–D). If the research agenda is expanding, as in divergent periods, the institutional setting and strategic funding measures are probably more effective if they provide critical mass and stimulate openness of project proposals based on excellent quality. On the other hand, if the research changes to a convergent pattern, policy steering instruments are to be used that accommodate to the requirements of gaining focus and stability in funding this research, e.g. stable budgets for clear research targets. Steering measures may, if so needed, also take a more pro-active form, anticipating or forging changes.

Genomics as a research field worldwide

The word 'genome' was first made in 1920 by a German botany professor, from the words ***gen**e* and *chromos**ome***, followed in the eighties by 'genomics' as the study of an organism's genome [LEDERBERG & MCGRAY, 2001].[1] The first genome entirely sequenced in 1980 was that of a single cellular organism. The international Human Genome Project (HUGO) completed a rough first draft of the human genome early 2001. Today, genomics is a potential source of novel applications in medicine, health, food and sustainable production [NGI, 2006]. In the wake of the technical successes of genomics, the use of the Greek suffix 'ome', meaning 'all', 'every' or 'complete' in 'gen-ome' has been translated to other areas, such as 'nutri-genomics' or 'eco-genomics'.

Looking at genomics research worldwide on the Internet it is clear from the data we gathered that the field has grown very rapidly over the last decade, after its entrance on the Web under the common denominator of 'genomics' around the year 1990 (Figure 2).[2]

The newer sub-areas of 'ecogenomics', 'nutrigenomics', 'toxicogenomics', 'metabolomics', form a relatively small portion on top of 'genomics' and 'proteomics' as seen from publications presented on the worldwide web. If we zoom in on the top layers of the graph (Figure 3) it is clear that 'toxicogenomics' is a rather stable area, at least as perceived on the internet, that is present from early in the nineties, whereas 'metabolomics', 'nutrigenomics' and 'ecogenomics' are the more recent genomics subfields.

The growth of these subfields, as of yet, however, doesn't provide a second boost of efforts.[3]

As a rough statement we conclude that genomics research showed dynamic growth in the last decade, starting to grow rapidly in the late nineties of the last century, and is now branching into several subfields, whereas the earlier expanding growth is now turning to a slower pace.

The data for the subsequent years were gathered from the internet using the 'Google Scholar Advanced Search' (GS) search engine [GOOGLE, 2006] for publications including 'Genomics', respectively 'Proteomics', 'Metabolomics', 'Toxicogenomics', 'Nutrigenomics' or 'Ecogenomics', anywhere in the article. Both in the genomics field as in the subfields we find that the growth curve is stabilizing or even going down somewhat. Thus, from these results it seems that the field is now far from exponential growth, indicating lower dynamics.

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[1] The term 'genomics' was coined in 1986 by three scholars as a catchword for a to be founded journal.

[2] We assume here that the development of the genomics research field and its sub-fields, is reflected in the use of keywords as 'genomics' in a linear fashion: that is, proportionally with total research output.

[3] According to DE SOLLA PRICE'S [1961, 1963] theory of the exponential growth, a research area stabilizes after a period of exponential growth, due to saturation, and then may start a new exponential growth.

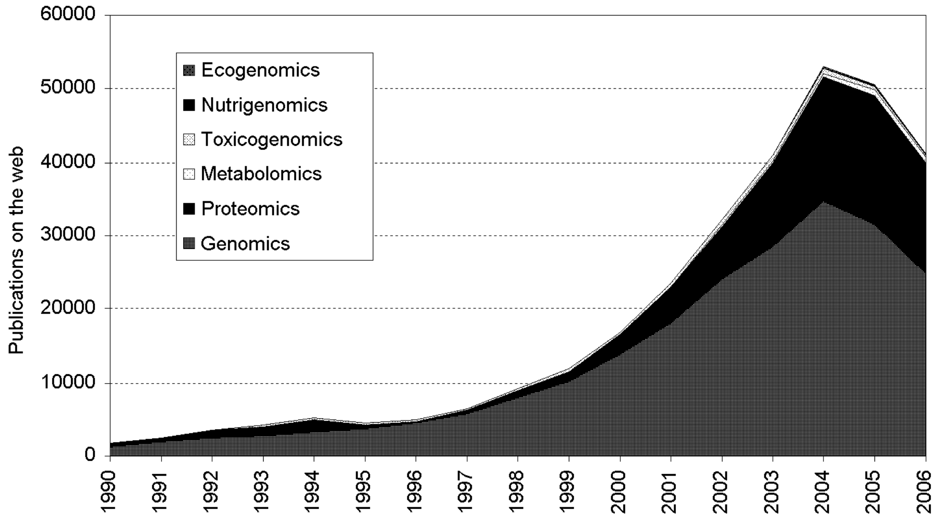

Figure 2. Genomics Worldwide
(Source: data searched at Google Scholar, 6th February 2007.)

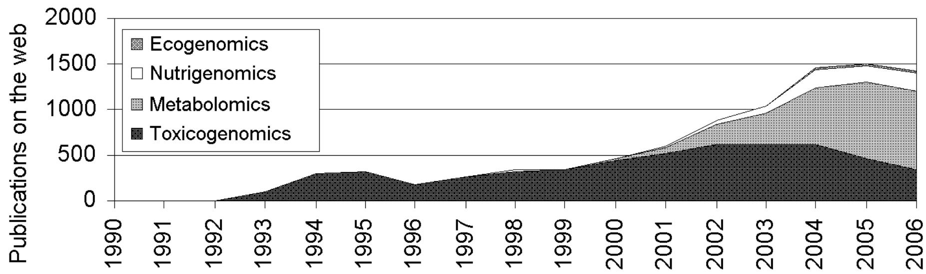

Figure 3. Genomics' minor subfields
(Source: data from Google Scholar, 6th Feb. 2007.)

It must be said that coverage of formal research publications by Google Scholar is limited, as shown by JACSÓ [2005]. But, citation counts across a wide range of disciplines, including molecular biology and ecology, offer comparable results, possibly caused by posting journal back-issues and author-draft versions on the web, as is shown by PAULY & STERGIOU [2005]. We therefore cautiously conclude, that our data and results on publication growth taken from the web indicate real developments in genomics. But, for an additional perspective we also performed a ‘genomics’ search on the HighWire Press, Stanford University Libraries, which hosts a repository of (links to) full-text articles from nearly 1000 peer reviewed journals.

The results are quite similar to what we found at GS, although the downward movement at the end of the time period is not so clear. In the HighWire Press online hosted journals, the figure of ‘genomics’ is steadily going up starting from the late nineties (Figure 4), indicating a steady-state growth of the genomics field.

The numbers of publications found for ‘genomics’ and its subfields[4] in the Web of Science[5] (Figure 5), also indicate that the genomics research field is entering a more steady growth pace.

For the moment, as a rough indication, we conclude that genomics research and its subfields worldwide are in steady growth, or may even be declining somewhat in popularity amongst researchers and their financers. However, this might be a period of rest before a new boost of growth, or stagnation due to lack of high throughput data analysis facilities to be developed.

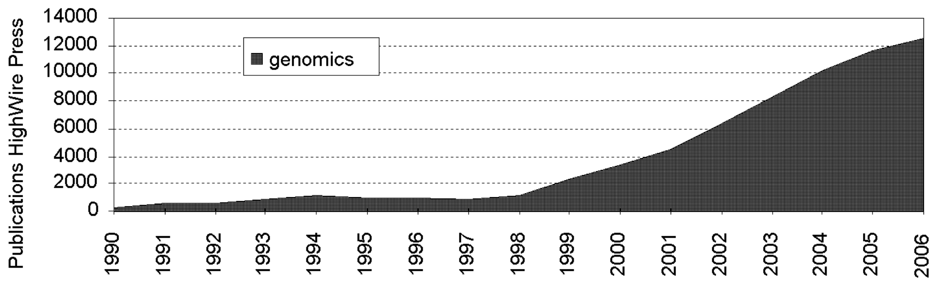

Figure 4. Genomics worldwide, at HighWire Press, Stanford University Libraries.
(Source: High Wire Press Online, 08-11-2006, figure for 2006, updated 14-02-07.
High Wire Press of Stanford University Libraries provides on-line repository hosting of some 1000 journals and about 4 million full text articles from over 130 scholarly publishers, including PubMed.)

[4] Subfields included ‘genomics’, ‘proteomics’, ‘metabolomics’, ‘toxicogenomics’, ‘nutrigenomics’ and ‘ecogenomics’, i.e. the same subfield indicators were taken as in searching at Google Scholar (Figure 2).

[5] The Thomson Scientific Web of Science provides access to current and retrospective multidisciplinary information from some 8700 high impact research journals worldwide. Approximately 850,000 fully indexed journal articles have been added to Web of Science, from 262 scientific journals (situation, 2006/7).

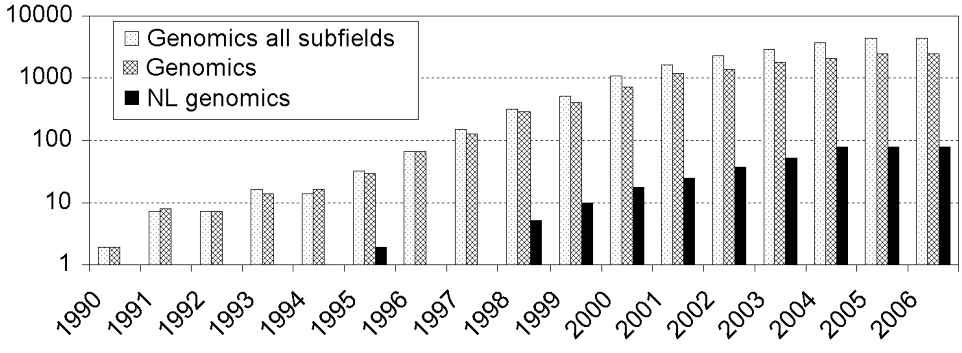

Figure 5. Genomics articles worldwide at Web of Science, Thomson
(Source: Web of Science, Thomson, 28 November 2006, updated 6th Feb. 2007.)

The national genomics initiative in the Netherlands

In the Netherlands the government has been supporting genomics research from the early years of this century, by establishing a National Genomics Initiative that stimulates novel research collaboration in genomics research networks and innovative application clusters. A sense of the dynamics of genomics also comes up from visiting the Genomics Momentum 2006 [NGI, 2006], where the various NGI Genomics Centers presented themselves together with government and business parties, in some 50 exhibit stands. The Genomics Momentum 2006, sponsored by four large industrial firms, a government agency for innovation and the City of Rotterdam, explicitly addresses NGI's future expectations under the title given: "Genomics: Ready for the next step". The several workshops provide an idea of what is meant by this follow up of "The 'Big Bang' of '-omics' that basically just happened" (see Table 1).

The Genomics Momentum 2006 shows that the Netherlands Genomics Initiative is aiming at a broad strategy for research on the one hand, and holds high expectations on the societal and economic revenues to be explored and harvested on the other. Lets turn to achievements now.

If we look at the Dutch contribution to worldwide genomics research (see again Figure 5), it seems that the Dutch curve follows the same path as worldwide research, though at a lower level, which is quite understandable if we take the size of the country into account. The contribution to genomics by research from the Netherlands, as seen in the Web of Science, is not evenly distributed over the several subfields, as seen in Figure 6 below.

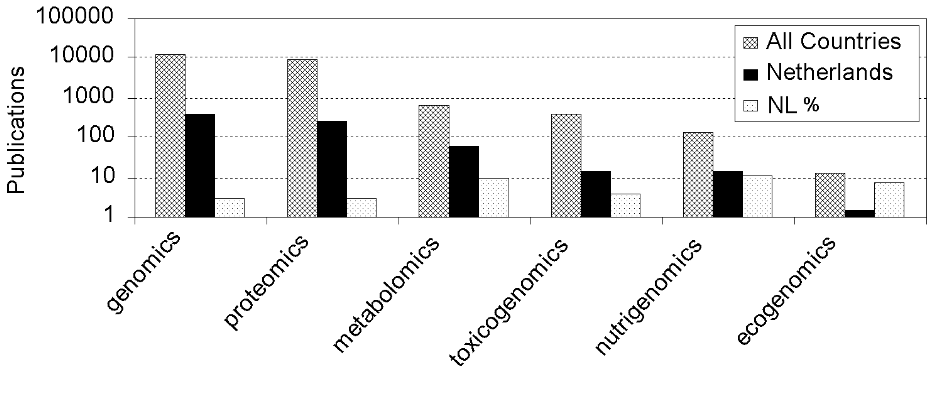

Figure 6. Dutch presence in genomics as reflected in Web of Science 1990–2006
(Source: search results at Web of Science, Thomson, 28 November 2006.)

The numbers here give an underestimate of all contributions, as only publications explicitly including 'genomics', or 'proteomics' etc., in the article text were selected for this instance.

NGI genomics centers

In order to study the dynamics of Dutch genomics research in more detail we used data from self-evaluation reports of these centers that were provided on behalf of the NGI by QANU.[6]

For the several Centers of Excellence, Platforms and Innovative Clusters, we have performed a somewhat more detailed analysis of academic research output, focusing on levels of growth, topical diversity and collaboration networks. Contrary to the worldwide data, for these centers only a limited number of years can be traced, as the subsidized research output is not older than 2002, and in some cases even of more recent date. Following BONACCORSI [2005] we looked at the growth of the number of publications from the different centers, as a measure of expansion of output in their research areas, and at the choice of journal titles chosen to publish in, as a measure of diversity of the scope of research at the centers. Collaboration patterns are also looked at as a further clue to the dynamics of genomics research. These three data together will be used to establish indicators of research dynamics at the different groups, or centers: do their research efforts follow a more diverging or converging (re)search regime?

[6] The Netherlands Genomics Initiative (NGI) recently commissioned an evaluation of its centres by QANU: Quality Assurance Netherlands Universities, and we were kindly permitted to use these data to provide additional information.

We have tracked down publication data and plotted tables for the programs of the genomics centers for growth of academic peer reviewed journal articles and for journal choice. As most of the programs just run for some years as of yet, and as journal choice is only a rough indicator of research scope, the results offer not more than a tentative indication of the search development in the programs and some differences between program dynamics. Not for all the twelve centers publication data were already available, or available in a form that could be used for our data gathering and analysis purposes. Therefore, some of the centers are not included here.

The research output of the NGI Genomics Centers is given below (Figure 7) as a first indicator of the dynamics of genomics in the Netherlands.

It seems clear from these results that the dynamics at the several centers included are not the same: some programs clearly expand, while others seem to stabilize or decline in output somewhat, perhaps only for the moment. Also, the starting date of the Centers' connection to NGI differs, which is of course reflected in both the output data and results. For some of the centers, in particular 'Ecogenomics', and 'Toxicogenomics', data have so far not been processed or are not available yet, and results are not included here. The establishment of a Centre for Metabolomics is part of the next strategic plan of NGI. It is apparent that the NGI covers with all these centers a very broad range of the worldwide genomics research universe. If we look at the NBIC Centre, output seems to be stabilized. As bioinformatics is a major tool for genomics research, and probably crucial for the future flourishing of genomics, it is good to remark here that bioinformatics is programmed in other NGI Centers as well. The same holds for research efforts in Society and Genomics (CSG), for which a dedicated Centre is established, but also attention is (to be) paid at each of the other NGI Genomics Centers.

We now turn to another indicator of research dynamics: change in journal scope (Table 2). The idea behind this indicator is that in an expanding field of research where new topics are explored and/or research efforts incline sharply, the choice of journals will reflect the broadening of scope and/or search of available extra journal space to publish the new amounts of output in. Therefore we looked at the number of articles that were published by the Centers in journals that were (first) used as output channels in the period under consideration (Figure 8).

Table 1. NGI Genomics Momentum 2006 workshops

Workshop	Titles
Workshop1	Metabolomics and quality of life: towards new initiatives and strategies
Workshop2	Toxicogenomics: assuring safety without animal testing
Workshop3	Towards a bio-based economy
Workshop4	Biobanks: from individual to collective concern
Workshop5	Living Healthier for longer: unexplored opportunities
Workshop6	E-bioscience: a new way of life (science)

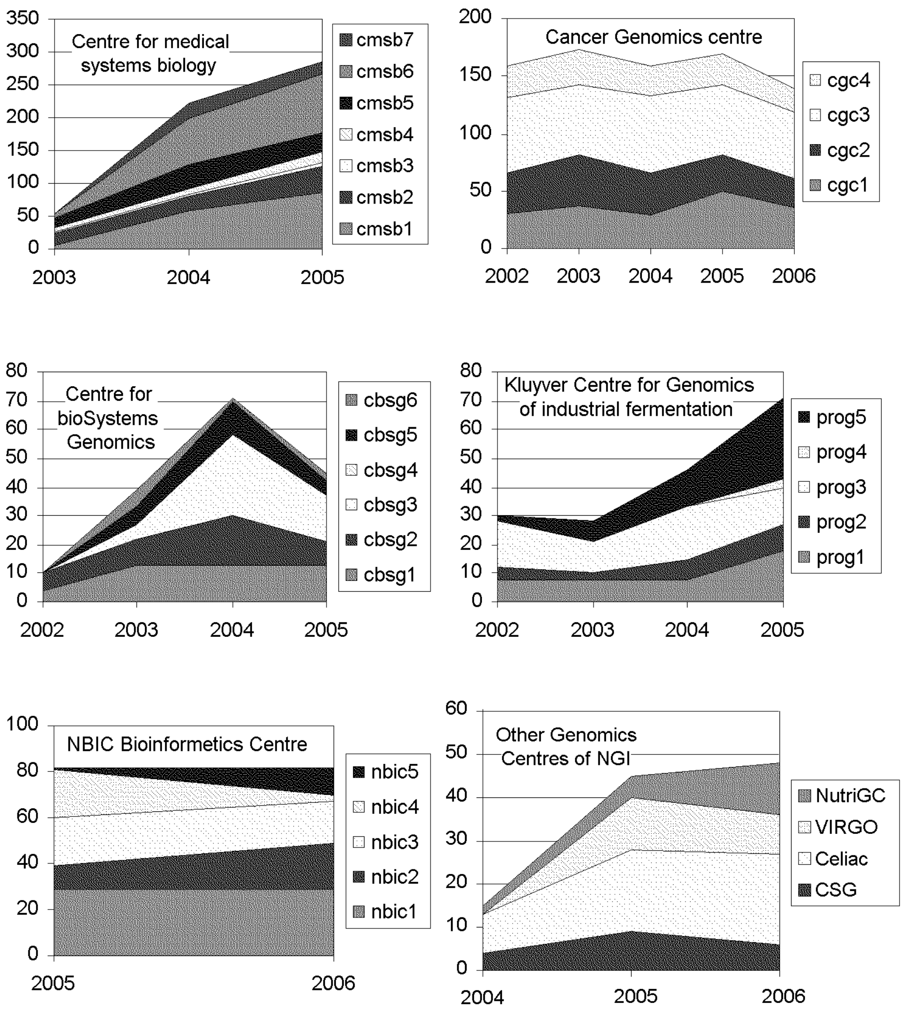

Figure 7. Growth of research output NGI Centers, as numbers of publications
Only articles in peer reviewed international journals included (and bioinformatics/computing conferences); figures for 2006 are here corrected by a factor 3/2 (adding a third of a years output) as a rough estimate of 2006 research output. For three of the NGI Genomics Centers, no sufficient data were available as of yet: Ecogenomics Center; Toxicogenomics Center; Proteomics Center

Table 2. Example of journal scope change in a research program

<table>
<tr><th>Celiac Disease Consortium, journal articles 2004–2006</th><th>2004</th><th>2005</th><th>2006</th><th>Total</th></tr>
<tr><td>PLOS Medicine (PLoS=public Library of Science)</td><td>|</td><td></td><td></td><td>1</td></tr>
<tr><td>Journal of Autoimmunity</td><td>|</td><td></td><td></td><td>1</td></tr>
<tr><td>GUT</td><td>||</td><td></td><td>|</td><td>3</td></tr>
<tr><td>European Journal of Human Genetics</td><td>||</td><td></td><td>|||</td><td>5</td></tr>
<tr><td>Genes</td><td>|</td><td></td><td></td><td>1</td></tr>
<tr><td>Gastroenterology</td><td>|</td><td>|||</td><td>|</td><td>5</td></tr>
<tr><td>American Journal of Gastroenterology</td><td>|</td><td></td><td></td><td>1</td></tr>
<tr><td>Journal of Life Sciences</td><td></td><td>|</td><td></td><td>1</td></tr>
<tr><td>Nature Genetics</td><td></td><td>|</td><td></td><td>1</td></tr>
<tr><td>Human Genetics</td><td></td><td>|</td><td></td><td>1</td></tr>
<tr><td>New England Journal of Medicine</td><td></td><td>|</td><td></td><td>1</td></tr>
<tr><td>Expert Review of Molecular Diagnostics</td><td></td><td>|</td><td></td><td>1</td></tr>
<tr><td>Biotechnology Advances</td><td></td><td>|</td><td></td><td>1</td></tr>
<tr><td>Am J Physiol Gastrointestinal Liver Physiology</td><td></td><td>|</td><td>|</td><td>2</td></tr>
<tr><td>Clin Chem Lab Med (Clinical Chemistry and Laboratory Medicine)</td><td></td><td>|</td><td></td><td>1</td></tr>
<tr><td>Best practice & research: clinical gastroenterology</td><td></td><td>|||</td><td></td><td>3</td></tr>
<tr><td>J Pediatr (The Journal of Pediatrics)</td><td></td><td>|</td><td></td><td>1</td></tr>
<tr><td>Genes and Immunity</td><td></td><td>|</td><td></td><td>1</td></tr>
<tr><td>Immunogenetics</td><td></td><td>|</td><td></td><td>1</td></tr>
<tr><td>European Journal of Gastroenterology and Hepatology</td><td></td><td>||</td><td>||</td><td>4</td></tr>
<tr><td>Tissue Antigens</td><td></td><td></td><td>|</td><td>1</td></tr>
<tr><td>Trends in Biotechnology</td><td></td><td></td><td>|</td><td>1</td></tr>
<tr><td>Human Immunology</td><td></td><td></td><td>||</td><td>2</td></tr>
<tr><td>American Journal of Human Genetics</td><td></td><td></td><td>|</td><td>1</td></tr>
<tr><td>BMC Genomics</td><td></td><td></td><td>|</td><td>1</td></tr>
<tr><td>Total articles</td><td>9</td><td>19</td><td>14</td><td>42</td></tr>
<tr><td>Journals</td><td>7</td><td>14</td><td>10</td><td>25</td></tr>
<tr><td>New journals (not used before)</td><td>7</td><td>13</td><td>5</td><td>–</td></tr>
<tr><td>Articles in new journals</td><td>7</td><td>16</td><td>6</td><td>–</td></tr>
<tr><td>Scope: % articles in new journals</td><td>100</td><td>84</td><td>43</td><td>–</td></tr>
</table>

Source: www.celiac-disease-consortium.nl/publications.asp

This example shows the basic journal publication data of the Celiac Disease Consortium used and clarifies how the scope indicator is calculated: for each journal all articles are plotted for subsequent publication years; the number of articles in new journals is given as a percentage.

The Table 2 shows that 84% of the publications of the Celiac Disease Consortium in the year 2005 (16 out of 19 articles) was in newly used journals. For each Centre that we could gather and analyze publication data, the results for this indicator of scope change are presented here (Figure 8) for all individual programs at these NGI Centers.[7]

[7] Data were gathered at the level of programmes, from the output lists on the web pages of the Centres, and/or – in collaboration with QANU - from the self-evaluation reports the Centres provided for an NGI-research review. Three Centres are left out here, as available publication data were insufficient.

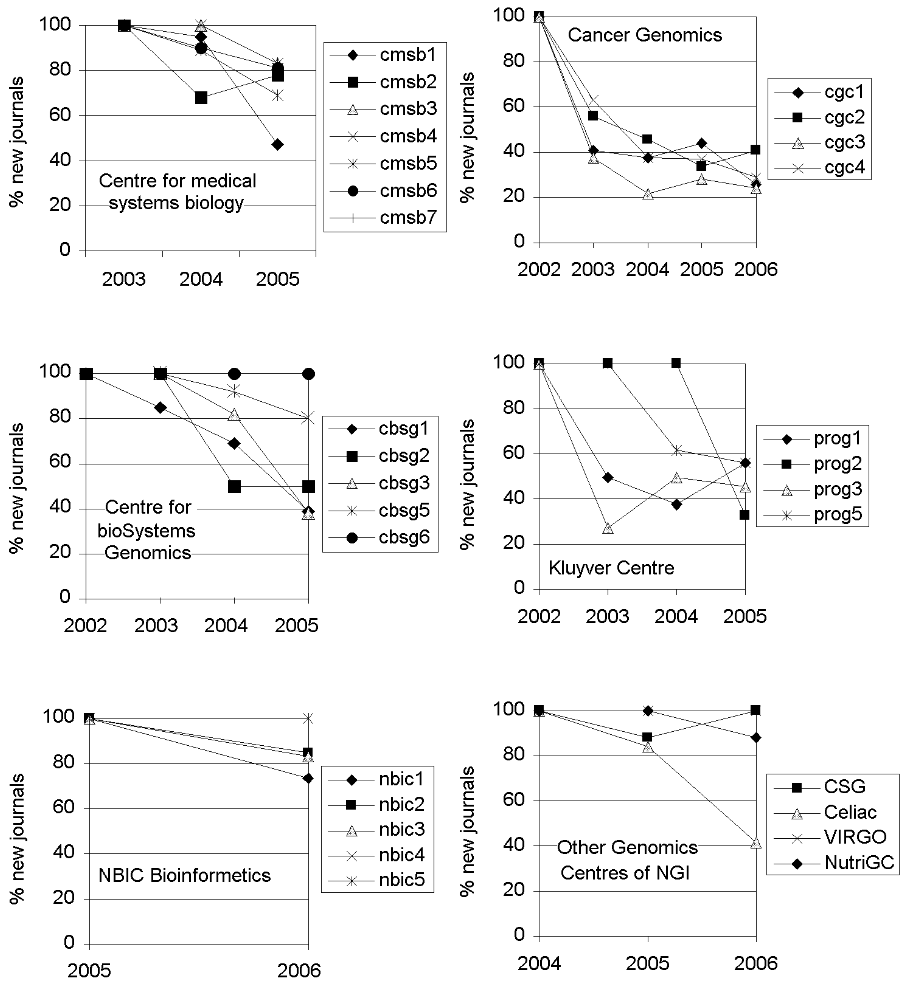

Figure 8. Scope changes of research output of NGI Centers, indicated by journal choice

From these figures it is clear that the dynamics at the Centers' programs show differences. In some cases, as in the Cancer Genomics Centre, the research programs seem quite stable in focus, whereas in other Centers, such as the Kluyver Centre and CBSG, the programs give a more mixed picture, some changing in scope more than others. For most of the programs at the different Centers it seems that the change in journals chosen to publish research output in, is rather high: many programs have over 40–50% published output in journals not used before for almost every year (in the period under consideration).

The general picture that arises from these results, preliminary as they are, may probably be that alongside some stable research areas in cancer research, biomedical research, industrial fermentation research and in systems biology, a probably expanding exploration of new concepts, tools and empirical data is going on in the programs, carried out by researchers in the networks associated with and around the NGI Centers.

According to BONACCORSI [2005], variety and abundance of collaborations provides a third indication of dynamics of research. We checked the number and type of partnerships of the NGI Genomics Centers from their fact sheets.[8]

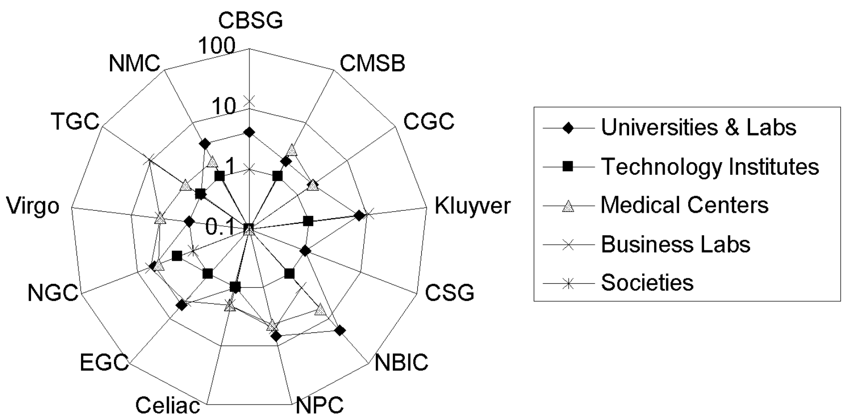

Figure 9a. Partnerships in Netherlands Genomics Initiative Centers

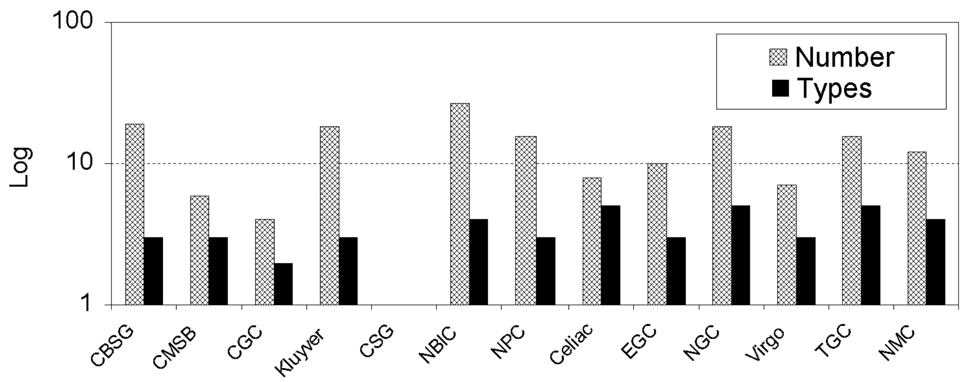

Figure 9b. Partnerships in Netherlands Genomics Initiative Centers

[8] Source: NGI Genomics Centres fact sheets taken from the NGI website: www.genomics.nl

The NGI Centers include from 4 to 27 institutional partnerships, with up to five different types (Figure 9a and 9b), including university departments, public financed laboratories, private company laboratories, university medical centers, or societies and boards related to industry. This holds, except for the Centre for Society and Genomics (CSG), doing research of a different nature. We conclude form these results, that the NGI Centers are working in an environment that enhances dynamic expansion of their findings and innovative opportunities.

Managing the future of genomics research: "Ready for the next step?"

Looking at the three calculated indicators of research dynamics for the NGI Centers, growth of publications, research focus and collaborations, we placed the centers in the timeframe of the above introduced research dynamics and management model (Figure 1 A–D). The estimates for the Centers are presented in Table 3, together with peer research review evaluation scores.

Table 3. Indicators of research dynamics and review scores for NGI Centres

NGI centers	Indicators of dynamics*				Assessments**				
	Growth	Focus	Collabo-ration	Model Phase	Center	Program review score averages			
						Q	P	R	V
CMSB	<	<	<	A	4	3.6	3,5	3,4	3.8
CGC	=>	>	>	C	5	4.8	4.8	5.0	5.0
CBSG	>	<=	<	C	4	3.8	3.3	4.0	4.5
Kluyver	<	>	<	B	4–5	4.0	4.2	4.3	4.2
NBIC	=	<	<	A	4	4.0	4.0	4.0	4.0
NutriGC	<	<	<	A	4	3.8	3.3	4.0	4.0
Virgo	>	<	<	A	4–5	4.0	4.0	4.0	4.2
Celiac	<	>	<	A	4	4.0	3.6	4.0	3.7
CSG	=	<	>	A	3–4	3.0	–	4.0	4.0

* Symbols: < expansion; divergent; complementary; > shrinkage; convergent; redundant; = stable; stable; neutral
** Research Review by international scientists committees: institute score, and averaged scores for program quality Q, productivity P, Relevance R, and program vitality V, review scores are given by committees in the following range: 5 = excellent; 4 = very good; 3 = good; 2 = satisfactory; 1 = unsatisfactory; Source: calculated from raw scores, QANU, 2007.[9]

The three indicators of dynamics seem to point to differences in research dynamics between the NGI Centers, some stabilizing (B), or converging (C), others with diverging research dynamics (A). Comparison with research evaluation results shows no strong correlations, except for a weak link with of scores on vitality. Centers indicated to be in phase C and B receive the highest scores on vitality, while the centers

[9] Research Review NGI Genomics Centres, Quality Assurance Netherlands Universities, QANU, 2007 all committee reports are publicly available at QANU at www.qanu.nl and at NGI at www.genomics.nl

in phase A receive somewhat lower scores on their assessed vitality. This – indeed rather tentative – result seems to ask for further research on the relation between research dynamics and research evaluation. Possibly, review committees favor stabilized or converging research programs when it comes to assessing their future prosperity, and are a bit on the guard for programs still searching to find their way.

Another question relates to research management and research policy. If research centers differ in their dynamics, from more diverging to converging phases, steering measures in financing research centers and programs within them, may ask for a more tailored approach. For example, in the Netherlands funding is often discussed along lines of providing ‘focus’ and/or ‘mass’ to research institutes and initiatives. Providing ‘mass’ to research in a divergent regime, helps in expanding the research agenda, but may also lead to fragmentation of research if an area is expanding too fast. Overcoming fragmentation of research efforts is precisely what the NGI tried to reach in the previous funding round. Providing more focus to research in a divergent regime (B) may then be a better policy solution, although one should be careful not to slow down research too much. Some of the NGI Centers (CCG and CBSG) seem to be more in a converging mode, and focused support (C) may be of help in research efforts zooming in, but one should be on the guard for too much rigor here not to freeze developments. If we could better relate these kinds of policy measures to differences in research dynamics, external steering of research might become both more effective and acceptable. For this purpose we have drawn a matrix of research policy effects that could be taken into account when discussing policy measures. For each combination of research dynamics and policy measures in the matrix, policy steering options are specified that relate to the timeframe of the research management model (see Figure 10).

<table>
<tr><th colspan="2" rowspan="2">Research Policy Discussion areas</th><th colspan="2">Research policy measure</th></tr>
<tr><th>Mass</th><th>Focus</th></tr>
<tr><td rowspan="2">Research dynamics</td><td>Divergent</td><td>A1 Expansion
/
A2 Fragmentation</td><td>B1 Orientation
/
B2 Slowing down</td></tr>
<tr><td>Convergent</td><td>D1 Consolidate
/
D2 Routine</td><td>C1 Accentuate
/
C2 Freeze</td></tr>
</table>

Figure 10. Research policy discussion areas

Conclusion and discussion

The picture arising from the indicators presented here, is that genomics research worldwide seems to be stabilizing, and coming in a period where new branches or subfield are coming up. Genomics research in the Netherlands, associated with the National Genomics Initiative, seems to be going along with this, but also prepares to enter a new phase of expanding both research and innovative explorations and applications in various sectors. As put by NGI at the Genomics Momentum 2006, Dutch genomics is getting 'ready for the next step'. If Dutch genomics research is to be at the forefront of this movement, as seems to be the aim, stimulating support may well mean different things for different NGI Research Centers, as their underlying dynamics seem to differ. Indicators on research dynamics could be of help in discussing steering options that best fit the development of research at the different Research Centers. The current collaboration patterns of the NGI Centers seem to be supportive of high dynamic development of Dutch Genomics, thus promoting genomics research in a 'next step'.

The general trend of stabilizing growth of Genomics worldwide is corroborated in other studies as well [ARCHAMBAULT & AL., 2003, P. 7]. Also, the quality of Dutch genomics research is underlined in this Canadian benchmark study, seen from size corrected ranking of countries. However, as in case of Canada, for smaller countries, quality and specialization seem better options than trying to grow along with the larger countries in all subfields quantitatively. The dynamics of Genomics Centers were here studied on a yearly comparison base, looking at publication growth and journal focus. In a recent study by CWST [VAN LEEUWEN & NEDERHOF, 2006] journal profiles were calculated for a longer time span (1996–2004). These profiles seem to corroborate the more stable journal focus of some of the NGI Centers we found (CGC, CBSG, Kluyver) and the more divergent character of other Centers (i.c. CMSB).

The results of this study are explorative and rather tentative. The indicators and publication resources explored provide only a rough picture of the dynamics of genomics and its sub-disciplines, of the Dutch contributions therein, the NGI-related Genomics Centers and their individual research programs. Comparison of indicator results with 'internal' views on the development of the field, coming from international review committees, points to unfavorable evaluation of more diverging research programs, as a possibility that should be examined. This points to one of the reasons why promoting innovative progress in research might profit from research steering measures that are more tailored to research dynamics. Longitudinal indicator studies on research dynamics could be helpful to gain more insight in these dynamics and may provide research management and policy makers with information that helps improve steering of research activities in relation to the changing dynamics of scientific research.

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