Report on the Birds-of-a-Feather Session at SC’13 in Denver

**Cost-Benefit Quantification for HPC: An Inevitable Challenge**

(Wednesday, November 20, 2013, bof167)

Contributors

- Thomas Ludwig, German Climate Computing Centre, Hamburg, Germany
- Sandra Wienke, RWTH Aachen University, Aachen, Germany
- Albert Reuther, MIT Lincoln Laboratory, Lexington, MA, USA
- Amy Apon, Clemson University, Clemson, SC, USA
- Earl Joseph, IDC Corporate, Framingham, MA, USA

Audience: the BoF attracted 50 participants. Most of them stayed until the end of the discussion.

High Performance Computing (HPC) is an indispensable though expensive technology. While the discussion of cost has been part of the conversation for many years, only recently have we also seen the analyses of its benefits. Quantification is difficult, and there is a need for robust economic models to evaluate the cost-benefit ratio and effects to efficiency in the industrial process and in scientific development. The BoF presented approaches to this issue and fostered a discussion between users and providers. A better understanding of the methods to quantify and qualify the benefit and cost aspects will result in cost efficient computational science and engineering.

The BoF started with a short presentation by Thomas Ludwig about the costs and benefits of HPC in computational science and engineering. Sandra Wienke talked about the cost-benefit aspects of using special hardware accelerators for parallel programs. Albert Reuther provided an overview of various ways to capture and quantify benefits of HPC for organizations. Amy Apon presented non-parametric efficiency estimators and their application in analyzing their use in assessing the effect of locally-available HPC resources on university research productivity. Earl Joseph presented IDC’s new project on this issue.

Presentations lasted about 65 minutes. After each talk we allowed a short three minutes discussion round. After the final presentation we had a general discussion of about 25 minutes.

The discussion covered many specific aspects of the individual talks. Several more general aspects were discussed and agreed upon by a large part of the audience:

- Academia knows very well how to buy huge systems. The knowledge in operating it cost-efficiently and also in using it cost-efficiently should be improved. Awareness on the side of the end users is still low.
- Experts in using HPC environments must pass this knowledge on to the graduate students.
- The BoF helps to raise the awareness for the issue of benefit and efficiency quantification.

New resources:
People in the audience asked for possibilities for further discussions and for further information material. A mailing list for discussions and information dissemination will be created in Jan 2014, and a web site will be launched by end of Jan 2014.

- Mailing list at [http://wr.informatik.uni-hamburg.de/cgi-bin/mailman/listinfo/cbq4hpc](http://wr.informatik.uni-hamburg.de/cgi-bin/mailman/listinfo/cbq4hpc)
Birds-of-a-Feather Session

Cost-Benefit Quantification for HPC
An Inevitable Challenge

Thomas Ludwig - German Climate Computing Center, Germany
Sandra Wienke - RWTH Aachen, Germany
Albert Reuther - MIT Lincoln Laboratory, USA
Amy Apon - Clemson University, USA
Earl Joseph - IDC Corporate, USA

Abstract

HPC is an indispensable though expensive technology. While the discussion of cost has been part of the conversation for many years, only recently have we also seen the analyses of its benefits. Quantification is difficult and we still lack an economical model to evaluate the cost-benefit ratio, and effects to efficiency, in the industrial process and in scientific development.

This BoF will present approaches to this issue and foster a discussion between investors and users.

Better understanding of the methods to quantify and qualify the benefit and cost aspects will result in cost efficient computational science and engineering.
Resources

• BoF Evaluation Form (please, please, please fill in!)

• SC ´13 program with BoF announcement

• Mailing list Cost-Benefit Quantification for HPC
  Subscribe here:
  http://wr.informatik.uni-hamburg.de/cgi-bin/mailman/listinfo/cbq4hpc
  in order to be in the CBQ4HPC mailing list

• We will set up a small web site with a collection of information and links
  http://www.cbq4hpc.org/
How it Began

SC ’12 in Salt Lake City
Invited talk of Thomas Ludwig with the title

“The Costs of HPC-Based Science in the Exascale Era”

Cited some interesting research papers and agreed with the authors upon the submission of a BoF proposal for SC ’13
Why this Topic?

• HPC is very costly and will become extremely expensive in the Exascale era – top systems will cost several $100 millions
• HPC is indispensable for progress in science
• HPC is indispensable for production in industry

• As it is so expensive we should try to maximize its benefit
• However, how can benefit be quantified?
• And can we properly quantify the costs?
• We also need a metric for purchase decisions of systems
• Define a business model for HPC-based science and engineering
Goal of the BoF

- Give an overview over existing ideas and approaches
- Stimulate discussions between investors, service providers, and users
- Get economy specialists involved
- Learn from business considerations in industry
- Make the business case for HPC-based science and engineering
- Optimize the benefit-cost ratio for HPC-based science and engineering
Protagonists

• Thomas Ludwig is CEO of DKRZ and professor for computer science at the University of Hamburg. His research focus is on parallel I/O and energy efficiency.

• Sandra Wienke is a research assistant at the Center for Computing and Communication at RWTH Aachen University, Germany. Her research interests include HPC on parallel heterogeneous architectures with emphasis on productivity and performance.

• Dr. Albert Reuther is the Assistant Group Leader of the Computing and Analytics group at MIT Lincoln Laboratory. In this role, he leads projects in HPC for rapid-prototyping, Big Data analytics, and novel computer architectures.

• Dr. Amy Apon is Professor and Chair of the Computer Science Division in the School of Computing at Clemson University. She also leads the Big Data Systems Research lab and is active in the academic scientific computing community.

• Dr. Joseph heads up IDC's HPC programs. IDC tracks all computers sold around the world each quarter. Earl also leads IDC's HPC User Forum, which has held 51 meetings. He also does consulting projects for major HPC user sites and with vendors.
Who Will Present What?

• The BoF will start with a short presentation by Thomas Ludwig, German Climate Computing Centre (DKRZ), about the costs and benefits of HPC in computational science and engineering.
• Sandra Wienke, RWTH Aachen University, Germany, will talk about the cost-benefit aspects of using accelerators.
• Albert Reuther, MIT Lincoln Laboratory, will provide an overview of various ways to capture and quantify benefits of HPC for organizations.
• Amy Apon, Clemson University, will present nonparametric efficiency estimators and their application in analyzing their use in assessing the effect of locally-available HPC resources on university research productivity.
• Finally, Earl Joseph from IDC will present a new project on this issue.
• We will discuss with participants their suggestions and ideas to conduct further research in this important field. Presentation slides and results of the discussion will be publicly available.
DKRZ costs the tax payer €16 million per year.

It consumes 17 GWh of electricity per year which cost €2.5 million.

Climate researchers produce many papers to participate in the IPCC Assessment Reports.

What is the papers per kWh ratio?
• Accelerators may boost performance in technical computing
• But, are they really worth the pain?
• Benefit-cost ratio approach by RWTH case study
  o Benefit: scientific results (= application runs)
  o Cost: total cost of ownership (TCO)
Each organization must weigh the impact priority of HPC activities

Find a way to concretely quantify the benefit in order to compare costs

The benefit of HPC to an organization depends on a number of factors
  - E.g. time saved per researcher or research team
  - E.g. impact on product sales.
Amy Apon
Clemson University
Clemson, SC, USA

- How to use nonparametric efficiency estimators to quantify the effect of locally-available HPC resources on research output
- Shows evidence that HPC instrumentation has a positive effect on universities' efficiency
- Locally-available HPC resources enhance the technical efficiency of research output in only some sciences
- The methods presented provide a critical step in a quantitative economic model for investments in HPC.
DOE funded research program aims at creating two macroeconomic models to show the linkage between investments in HPC and the resulting financial ROI and innovation.

The models also include a new innovation index.

Questions

Would you like to participate in the next phase of the ROI study?

Would you like to become a spokesperson on the ROI topic in your sector or for your country?
The Cost/ Benefit Situation at DKRZ

Prof. Dr. Thomas Ludwig

German Climate Computing Centre & University of Hamburg
Hamburg, Germany
ludwig@dkrz.de
DKRZ in Hamburg

Deutsches Klimarechenzentrum (DKRZ)
German Climate Computing Centre
IBM Power6 Computer System

- Rank 368 in TOP500/Jun13
- 8,064 cores, 115 TFLOPS Linpack
- 6PB disks
Sun StorageTek Tape Library

• 100 PB storage capacity
• 90 tape drives
• HPSS HSM system
5th IPCC status report:

- German part uses ca. 30M corehours at DKRZ
- DKRZ offers ca. 60M corehours/y
- Energy costs for the German IPCC contribution: \( \text{ca. } €1 \text{ m} \)
  - 9,000,000 kWh to solution with DKRZ’s Blizzard system
  - 4,500 metric tons of CO₂ with regular German electricity

Climate researchers should predict the climate change...

... and not produce it!
TCO of DKRZ per year: approximately €16M
€8M hardware, €2M electricity, €3M brainware

Publications per year: let’s assume 100
Mean price per publication: €160,000
+ costs for scientists 😊

It is tax money – society expects a benefit
Example IPCC AR5 production runs

• Remember
  
  Energy costs for the German IPCC contribution: ca. 1 M€
  – 9,000,000 kWh to solution with DKRZ’s system
  – 4,500,000 kg of CO₂ with regular German electricity

• Approach: Tune program and save 10% runtime
  • Saves 900,000 kWh
  • Saves €100,000 (is one person year)
  • Saves 450 metric tons CO₂
Invest in people!

We need more HPC specialists

- Co-design and code development
- Tuning of applications
- many other things...

Gigadollars for iron and electricity will not be the solution!
Accelerators in Technical Computing: Is it Worth the Pain?

A TCO Perspective

Sandra Wienke, wienke@rz.rwth-aachen.de
Dieter an Mey, Matthias S. Müller

Cost-Benefit Quantification for HPC - An Inevitable Challenge
BOF, SC 2013, Denver

Publication: ISC’13, LNCS 7905, pp. 330-342

Center for Computing and Communication, Rechen- und Kommunikationszentrum (RZ)
**Motivation & Definition**

- **How it began**
  - **Accelerators – Awesome or Harmful?**

- **Decision making by “worth”**
  - Purchase one system or another
  - Use one programming model or another

- **Cost-benefit quantification (case study)**
  - **Cost**: TCO (total cost of ownership)
    - Include costs for manpower (development, administration)
  - **Benefit**: “amount of science”
    - Expressed in number of results within time period
    - Here: number of runs of a single application (w/o weights)

**CBR** = \( \frac{cost}{benefit} = \frac{TCO}{#app.runs} \)
Methodology

- **Aim:** compare architectures (& programming models)
  - Here: Intel Xeon server, NVIDIA Fermi GPU, Intel Xeon Phi

- **Modeling depends on architecture & application**
  - Here: (small) engineering application with 90% kernel portion

- **Basis:** single compute node ➔ extrapolate to cluster amount (no MPI)

- **Investment** \( I = TCO(n, \tau) = C_{ot}(n) + C_{pa}(n) \cdot \tau \)
  - One-time costs \( C_{ot} \), e.g. HW acquisition, prog. effort
  - Annual costs \( C_{pa} \), e.g. compiler/software, power consumption, app. maintenance

- **Cost-benefit ratio (CBR): costs per application run** \( C_{ar} \)
  - Includes investment/ TCO & application performance

\[
\text{CBR} = \frac{\text{cost}}{\text{benefit}} = C_{ar}(n, \tau) = \frac{TCO(n, \tau)}{ar(n, \tau)} \quad \text{with} \quad ar(n, \tau) = n \cdot \frac{\tau \cdot \text{usagerate}}{t_{par}}
\]
Results of Case Study

- **Target: decrease**
  1. Keep benefit, decrease costs
  2. Keep cost, increase benefit
  3. Both: decrease costs + increase benefit

- **Case study**

![Graph](image)

- **Lower is better.**
- **NOTE:** Range [0;0.015] omitted!

**GPU:** NVIDIA Tesla C2050 (Fermi)
**Phi:** Intel Xeon Phi 5110P, 60 cores
**SNB:** 2x Intel Sandy Bridge, 16 cores, 2 GHz
Results of Case Study

- **Baseline:** OpenMP-simp on SNB
- **GPU:** NVIDIA Tesla C2050 (Fermi)
- **Phi:** Intel Xeon Phi 5110P, 60 cores
- **SNB:** 2x Intel Sandy Bridge, 16 cores, 2 GHz

**Programming effort impacts break-even investment. Break-even investment increases proportionally with kernel size.**

**Kernel portion is crucial. Here: Accelerators are not beneficial for smaller kernel shares.**

**NOTE:** Range [0;0.25] omitted!
Summary & Conclusion

- Costs: TCO of HPC cluster environment
  - Including costs for manpower effort
  - Difficult to quantify all values ⇔ but, (fix) metrics

- Benefit: scientific results ~ #app. runs
  - Some weaknesses ⇔ but, easy number & useful for first approach

- Cost-benefit ratio: cost per app. run
  - Depending on own environment & application
  - Useful to compare systems (& prog. models)

- Our CBR case study results (no general conclusion)
  - Fermi GPU good, Xeon Phi not
    - Account sensitivity about input parameters!
      (e.g. Xeon Phi’s high acquisition costs had main impact)
  - Accelerators only worth w/ high amount of kernel portion

Thank you for the attention!
Quantifying Benefit for HPC

Albert Reuther
MIT Lincoln Laboratory

IEEE/ACM Supercomputing Birds of a Feather

November 20, 2013

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ROI = \frac{\text{Benefit}}{\text{Cost}}

\text{Cost} = \text{time to parallelize} + \text{time to train} + \text{time to launch} + \text{time to admin.} + \text{system cost}

\text{Benefit} = \text{Researcher parallel coding time} + \text{Researcher training time} + \text{Queuing and launch overhead} + \text{Sys-admin cost} + \text{Expert consultants} + \text{Computer cost} + \text{Facilities cost} + \text{Utilities}
Capability vs. Capacity Computing

**Capability Computing**
- National shared asset
- Enables previously unreachable results
- Focus: Wisely use precious resource

**Capacity Computing**
- Many more powerful binoculars
- Computational time/effort/force multiplier
- Focus: Wisely make users more productive

Source: wikipedia.com
Source: http://www.idas.org.uk

Kitt Peak National Observatory
Telescope Party
### Various Methods of Benefits

**Financial and Competitive Return**
- **ROI**
  - Shorter time to market
  - Shortened product development cycle
  - Effective supply chain mgmt.
- Reduced design costs
- Fewer physical tests
  - Quality and reliability
  - Risk reduction
  - “Explore digitally, confirm physically” (mantra at P&G)
- Critical to business/product development
- Breakthrough products

**Research Return**
- Research productivity
- Broader insight
- Research funding/competitiveness
- Entries in Top500 list
- Cover articles in *Science*
- Number of NSF grants

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Council on Competitiveness: Compete.org
Industry Benefits – Examples

Why Does HPC Matter?
(Industry Survey)

- Could still exist and compete: 3%
- Could not exist as a business: 47%
- Unable to compete: time to market and cost issues: 34%
- Unable to compete: product testing and quality issues: 16%

Sources:
- Boeing and HPC for Energy
- GM and Council on Competitiveness
- DreamWorks and Council on Competitiveness
- Procter & Gamble Co. and Council on Competitiveness
- Chevron/Texaco and Council on Competitiveness

Industry Benefits – Examples

- Aircraft Design
- Vehicle Crash Tests
- Movie Rendering
- Sports Equipment Validation
- Container Optimization
- Oil Field Exploration

Sources:
- PING and Council on Competitiveness
- Council on Competitiveness: http://www.compete.org/
- HPC for Energy: http://hpc4energy.org/
Research Benefits

- **Research Productivity**
- **Broader insight/risk reduction**
- **Research competitiveness**
- **Entries in Top500 list**
- **Cover articles in Science/Nature/Cell/etc.**
- **Number of NSF and other grants**

Source: cell.com
Source: usnews.com
Source: qualitymatters.org
Source: nature.com
Source: sciencemag.org
Source: Council on Competitiveness: http://www.compete.org/


Lincoln’s Leadership in Interactive, On-Demand Supercomputing

- Lincoln’s research mission requires interactive supercomputing
  - Primarily for the development of sensor processing systems
- Lincoln has the largest interactive capability in DoD
- EcoPOD facility allows competitive position to be maintained

**EcoPOD Capacity:**
- 1500 nodes
- 0.5 Petaflops
- 0.4 Petabyte RAM
- 15 Petabyte Disk
- 44 racks
- 1 Megawatt

**HP EcoPOD:** high efficiency, deployable data center

**Lincoln’s Leadership in Interactive, On-Demand Supercomputing**

- Lincoln’s research mission requires interactive supercomputing
  - Primarily for the development of sensor processing systems
- Lincoln has the largest interactive capability in DoD
- EcoPOD facility allows competitive position to be maintained
LLGrid Core Capabilities
LLGrid is a System-of-Systems

### Common Interactive Architecture

#### LLGrid Core Capabilities

**Cluster(s)**
- TX-2500
- TX-Green
- TX-3D
- TX-C
- TX-2400
- TX-BW
- TX-CySA
- TX-D2D
- TX-SRC

**Classification**
- Unclassified
- Unclass
- Class
- Class
- Class
- External
- CySA
- External
- Unclass

**Labwide**
- Labwide
- Labwide
- Div3
- PL-2 Labwide
- PL2 SIPRNet
- Open
- Limited
- U/FOUO
- Labwide

**F1**
- EcoPOD
- F4
- F1 -> EcoPOD
- F1 -> EcoPOD
- MGHPCC
- F1
- F1
- EcoPOD

**FLCONS**
- F1
- EcoPOD
- F4
- F1 -> EcoPOD
- MGHPCC
- F1
- F1
- EcoPOD

**Compute Nodes**
- 578 40
- 274 270
- 100
- 40
- 200
- 24
- 22
- 20

**Compute Cores**
- 1256 1280
- 8768 540
- 3200
- 1280
- 6000
- 576
- 704
- 320

**Peak Performance (TFLOPs)**
- 46 10
- 77.1
- 6.9
- 28.2
- 11
- 50
- 4.8
- 48.3
- 2

**RAM (TB)**
- 4
- 17.5
- 4.9
- 9.6
- 3.8
- 10
- 1.5
- 2.1
- 2.1

**Central Storage (TB)**
- 1,509
- 1,200
- 54
- 100
- 96
- 1,000
- 0
- 200
- 200

**Distributed Storage (TB)**
- 682 360
- 2,466
- 408
- 900
- 240
- 1,000
- 288
- 132
- 132

### Diverse Locations

#### Holyoke EcoPOD

**Now Winter Fall**

#### MGHPCC

**Now**

**LINCOLN LABORATORY**
Massachusetts Institute of Technology
Quantifying the HPC Research Productivity Benefit

\[ \text{ROI} = \frac{\text{Benefit}}{\text{Cost}} \]

**Reciprocal Jobsize Scaling**

\[ B = S \sum_{\text{all jobs}} (\text{JobDur} \times (1 - \frac{1}{\# \text{subjobs}})) \]

**Linear Jobsize Scaling**

\[ B = S \sum_{\text{all jobs}} (\text{JobDur} \times \# \text{subjobs}) \]

**Logarithmic Jobsize Scaling**

\[ B = S \sum_{\text{all jobs}} (\text{JobDur} \times \log_2(\# \text{subjobs})) \]

\[ B = \text{benefit} \quad S = \text{fully-burdened researcher salary} \]

- **time to parallelize**
- **time to train**
- **time to launch**
- **time to admin.**
- **system cost**
## LLGrid Productivity Analysis

Productivity (ROI) = \left( \frac{\text{time saved by users on system}}{\text{time to parallelize}} + \text{time to train} + \text{time to launch} + \text{time to admin.} + \text{system cost} \right)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>FY2007 2 new systems</th>
<th>FY2010 no new systems</th>
<th>FY2013 3 new systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab-wide Users</td>
<td>364</td>
<td>711</td>
<td>1017</td>
</tr>
<tr>
<td>New Users in Latest Year</td>
<td>63</td>
<td>60</td>
<td>83</td>
</tr>
<tr>
<td>Active Users in Latest Year</td>
<td>105</td>
<td>153</td>
<td>218</td>
</tr>
<tr>
<td>Avg. Simultaneous Jobs</td>
<td>48</td>
<td>65</td>
<td>55</td>
</tr>
<tr>
<td>Avg. CPUs per Job</td>
<td>29</td>
<td>94</td>
<td>65</td>
</tr>
<tr>
<td>Total Job Launches</td>
<td>47,043</td>
<td>226,839</td>
<td>89,270</td>
</tr>
<tr>
<td>Number of System Administrators</td>
<td>7</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Nodes in System</td>
<td>748</td>
<td>937</td>
<td>926</td>
</tr>
<tr>
<td>New Nodes in System (Latest Year)</td>
<td>748</td>
<td>0</td>
<td>414</td>
</tr>
<tr>
<td>Benefit/Cost (Linear: CPUs)</td>
<td>41.6</td>
<td>263.0</td>
<td>115.7</td>
</tr>
<tr>
<td>Benefit/Cost (Logarithmic: \log_2(CPUs))</td>
<td>4.6</td>
<td>27.6</td>
<td>9.1</td>
</tr>
<tr>
<td>Benefit/Cost (Reciprocal: 1-1/CPUs)</td>
<td>0.99</td>
<td>5.4</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Efficiency as a Measure of Knowledge Production of Research Universities – Application to HPC ROI

Amy W. Apon* Linh B. Ngo*
Michael E. Payne* Paul W. Wilson+

School of Computing* and Department of Economics +
Clemson University
Using efficiency as a measure

- Extends traditional metrics
- Utilizes non-parametric estimation of relative efficiency of production units
- Avoids regression framework
- Takes scale of operation of institution into consideration
- Is supported by rigorous hypothesis testing
Efficiency is calculated as an estimate of a frontier of production

- We define \( P \) as the set of feasible combinations of \( p \) inputs and \( q \) outputs, also called the production set.

\[
P = \{(x, y) \in \mathbb{R}_+^{p+q} \mid x \text{ can produce } y\}
\]

- The production set is closed.
- The efficiency score measures the distance from the frontier.
- Efficiency must be estimated since it is unobserved.
Tests for equivalent means and for stochastic dominance

- Test for equivalent means
  - $H_0: \mu_1 = \mu_2$ versus $H_1: \mu_1 > \mu_2$

- Test for first order stochastic dominance between the two efficiency distributions:
  - $H_0$: Distribution 1 does not dominate Distribution 2
Shape of frontier

Test for Convexity

Convex

Convex

Not Convex

Test for Returns to Scale

Variable returns to scale

Constant returns to scale

Input

Output

Input

Output

Input

Output
HPC institutional data

• Leveraging the historical record of the Top 500 list
  – An historical record without comparison
• Steps in data preparation include corresponding the HPC site with its associated academic institutions
• Classification of HPC capability for our study
  – Have versus Have nots: Whether an institution has a Top500 system between 2000-2006
Department data description

• National Research Council: Data-Based Assessment of Research-Doctorate Programs in the U.S. for 2005-2006
• Input: Faculty Count, Average GRE Scores
• Output: PhD Graduates, Publication Counts
• 8 academic fields have sufficient data:
  – Chemistry
  – Civil and Environmental Engineering
  – Computer Science
  – Ecology and Evolutionary Biology
  – English
  – Economics
  – History
  – Physics
## Tests for convexity, CRS

<table>
<thead>
<tr>
<th>Department</th>
<th>Test for Convexity</th>
<th>Test for Constant Returns to Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry</td>
<td>0.47</td>
<td>0.06</td>
</tr>
<tr>
<td>Civil/Environmental</td>
<td>0.90</td>
<td>0.99</td>
</tr>
<tr>
<td>Computer Science</td>
<td>0.37</td>
<td>0.99</td>
</tr>
<tr>
<td>Ecology/Evolutionary Biology</td>
<td>0.73</td>
<td>0.99</td>
</tr>
<tr>
<td>Economics</td>
<td>0.44</td>
<td>0.28</td>
</tr>
<tr>
<td>English</td>
<td>&lt; 0.01</td>
<td>--</td>
</tr>
<tr>
<td>History</td>
<td>&lt; 0.01</td>
<td>--</td>
</tr>
<tr>
<td>Physics</td>
<td>0.21</td>
<td>0.99</td>
</tr>
</tbody>
</table>
Tests for equivalent means
Stochastic dominance

<table>
<thead>
<tr>
<th>Have &gt; Have not</th>
<th>Equiv. means</th>
<th>St. Dom.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Civil/Environmental</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Computer Science</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Ecology/Evolutionary Biology</td>
<td>0.99</td>
<td>--</td>
</tr>
<tr>
<td>Economics</td>
<td>1.00</td>
<td>--</td>
</tr>
<tr>
<td>English</td>
<td>&lt; 0.01</td>
<td>0.95</td>
</tr>
<tr>
<td>History</td>
<td>&lt; 0.01</td>
<td>0.65</td>
</tr>
<tr>
<td>Physics</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>
Issues and Concerns

• Scarcity of useful data
  – Comparing different abstraction level needs datasets that can produce similar inputs/outputs
  – Longitudinal data

• Integration and curation of existing data

• A lower efficiency estimate does not mean a program is not doing well
  – Factors to consider include the characteristics of the admitted population, institutional goals and mission, etc.
Future Work

Our results raised interesting observations – why?

- What are the factors that make one set of institutions more efficient than the other?
- How is the nature of research different in more efficient institutions?
Efficiency as a Measure of Knowledge Production of Research Universities – Applications to HPC

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ROI And HPC Research Study: 
Creating Economic Models 
For Financial ROI And Innovation 
From HPC Investments 

November, 2013 

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A pilot study that describes how HPC investments are related to improved economic success and increased scientific innovation

The study included creating two unique models:
1. A macroeconomic model which depicts how HPC investments result in economic advancements in the form of ROI, growth and jobs
2. An "Innovation Index" that measures and compares innovation levels, based on the level of applying HPC computing resources towards scientific and technical advancement
The Financial ROI Models That Were Developed

The Financial ROI models include:

1. ROI based on revenues/GDP generated, divided by HPC investment
2. ROI based on profits generated, divided by HPC investment
3. ROI based on jobs created (and the HPC investment required per job created)

The ROI models were tested for variances by:

- Industry sector
- Country
- Organization size
The Innovation Models That Were Developed

The Innovation models are of two main types:

1. Basic Research / Major Innovations
2. Applied Research / Incremental Innovations

These are captured as:
- Innovations in government & academia
- Innovations in industry

The Innovation models can be sorted for variances by:
- Industry sector
- Country
- Organization size
- Government, Industry and Academia
The Innovation Index Scale

10 = One of the top 2 to 3 innovations in the last decade
9 = One of the top 5 innovations in the last decade
8 = One of the top 10 innovations in the last decade
7 = One of the top 25 innovations in the last decade
6 = One of the top 50 innovations in the last decade
5 = It had a major impact and is useful to many organizations
4 = A minor innovation that is useful to many organizations
3 = A minor innovation or only useful to 2-3 organizations
2 = A minor innovation or only useful to 1 organization
1 = An innovation that is recognized ONLY by experts in the field
Key Findings

• IDC is able to collect the required data across a broad set of organizations, with enough detail to create the economic models and the innovation index

• Early results indicate very substantial returns related to investments in HPC, on average:
  ➢ $356.5 in revenue per dollar of HPC invested
  ➢ $38.7 of profits/cost savings per dollar of HPC invested
  ➢ The average HPC investment per innovation was $3.1M

• Note that an additional outcome of this research is an expansive list of HPC success stories
Sample Characteristics

Sample demographics:

• **A total of 208 case study examples of ROI and innovations were collected as part of the study:**
  - 67 financial ROI examples
  - 141 innovation examples

• In addition, a large number of micro-surveys were conducted to learn key ratios in order to eventually apply the results to large economic data sets.
  - Over 30,000 scientists and engineers were contacted, with over 1,500 completing the micro-survey.
For each sector we need 4 basic ratios

- % That Conduct R&D
- % That Don’t Conduct R&D
- % Already Using Max HPC
- % That Could Use More HPC

Note: IDC has conducted over 30,000 light phone calls for this data. We will likely require 5x to 10x more surveys.
Pilot Study
Results:
Financial ROI
1. IDC is able to collect the required data across a broad set of organizations with enough detail to create the two economic models and the innovation index.

2. Early results indicate very substantial returns for investments in HPC:
   - $356 dollars on average in revenue per dollar of HPC invested.
   - $38 dollars on average of profits (or cost savings) per dollar of HPC invested.
Key Findings:
The Financial ROI Model – By Sector

<table>
<thead>
<tr>
<th>Organization Size: People (All)</th>
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<tbody>
<tr>
<td>Organization Size in $M (All)</td>
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<tr>
<td>Organization Size (S,M,L) (All)</td>
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<td>Industry (All)</td>
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<td>Innovation Level (All)</td>
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### Key Findings: The Financial ROI Model – By Country

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<th>Average of Revenue $ per HPC $</th>
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<tr>
<th>Country</th>
<th>Count</th>
<th>Employee Growth</th>
<th>Years Before 1st Return</th>
<th>Revenue $ per HPC</th>
<th>Profit $ per HPC</th>
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<td>China</td>
<td>3</td>
<td>30</td>
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<td>France</td>
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<td>UK</td>
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<td>896</td>
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<td>366.5</td>
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<td>Italy</td>
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<tr>
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<td>67</td>
<td>1,169</td>
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<td>356.5</td>
<td>38.7</td>
</tr>
</tbody>
</table>
Pilot Study Results: Innovation
Key Findings: Investments Per Innovation

The average HPC investment per innovation was $3.1 million.

- Overall $497 million in HPC investments were made to generate the 141 innovations in the pilot study.
- With many at under $1 million per innovation.
### Key Findings: The Innovation Areas For The 141 Innovation Data Examples

#### Table: Innovation Areas Summary

<table>
<thead>
<tr>
<th>Primary Innovation / ROI Area</th>
<th>Count</th>
<th>Sum of Total HPC Investment</th>
<th>Average Years Before 1st Return</th>
<th>Average of HPC $M per Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better Products</td>
<td>54</td>
<td>$114 M</td>
<td>1.9</td>
<td>$4.2 M</td>
</tr>
<tr>
<td>Created New Approach</td>
<td>40</td>
<td>$15 M</td>
<td>1.2</td>
<td>$0.4 M</td>
</tr>
<tr>
<td>Discovered Something New</td>
<td>20</td>
<td>$46 M</td>
<td>1.8</td>
<td>$2.7 M</td>
</tr>
<tr>
<td>Helped Society</td>
<td>11</td>
<td>$66 M</td>
<td>1.0</td>
<td>$6.0 M</td>
</tr>
<tr>
<td>Cost Saving</td>
<td>6</td>
<td>$180 M</td>
<td>1.3</td>
<td>$2.1 M</td>
</tr>
<tr>
<td>Major Breakthrough</td>
<td>5</td>
<td>$3 M</td>
<td>3.2</td>
<td>$1.1 M</td>
</tr>
<tr>
<td>Helped Research Program</td>
<td>5</td>
<td>$71 M</td>
<td>1.5</td>
<td>$14.3 M</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>141</strong></td>
<td><strong>$497 M</strong></td>
<td><strong>1.6</strong></td>
<td><strong>$3.1 M</strong></td>
</tr>
</tbody>
</table>
Key Findings: The New Innovation Index Scores

The average innovation rating = 5.0
• 4.4 for the 67 basic research/major innovations
• 5.5 for the 74 applied research/incremental innovations

10 = One of the top 2 to 3 innovations in the last decade
9 = One of the top 5 innovations in the last decade
8 = One of the top 10 innovations in the last decade
7 = One of the top 25 innovations in the last decade
6 = One of the top 50 innovations in the last decade
5 = It had a major impact and is useful to many organizations
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3 = A minor innovation or only useful to 2-3 organizations
2 = A minor innovation or only useful to 1 organization
1 = An innovation that is recognized ONLY by experts in the field
Key Findings: The New Innovation Index Scores – For All 141 Innovations

FIGURE 12

HPC Innovation Index Scale Results: All Respondents

(Number Of Innovations)

<table>
<thead>
<tr>
<th>Innovation Index Scale</th>
<th>Number of Innovations</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5</td>
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<tr>
<td>9</td>
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<td>8</td>
<td>15</td>
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<td>5</td>
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<td>4</td>
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<td>3</td>
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<tr>
<td>2</td>
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<tr>
<td>1</td>
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</tr>
</tbody>
</table>

N = 141

Source: IDC 2013
Key Findings: Locations of the Innovations

Academic and industrial sites represented the bulk of the innovations in the sample.

- Most of the basic research innovations were in academia, while most of the applied research innovations were in industry.

Government innovations were higher on the innovation index scale (averaging 7.0).

- Innovations in industry ranked lower at 5.7.
- Academic innovations averaged 3.9.
Note that an additional outcome of this research is an expansive list of HPC success stories.

- These can be used to help explain the importance of HPC to funding bodies, key decision makers and the broader public.
- IDC is writing up a number of them for broader dissemination.
The report and excel models will be posted at: www.hpcuserforum.com/ROI

Once approved by DOE, IDC will send the report and models to ~4,500 people in the broader HPC community.

IDC will brief the community at SC13
- On Tuesday during the IDC breakfast briefing
- On Wednesday, at 5:30 – 7:00pm, during the Cost-Benefit Quantification for HPC BOF

Press release

Many briefings have already been given – does DOE have additional briefings that IDC should conduct?
**Future ROI Research Plans (Proposed)**

**Phase I (Year 1)** – The goal is to create the actual ROI models with a full data set at least 2x in Phase I, growing to at least 8x in size by Phase III. This is needed to create predictive models a fuller understanding of the relationships, to provide enough data/analysis to start making predictive results, and to refine the models as needed.

- The goal is to have enough data to start making statistically sound correlations between industries, between countries and between different sizes of organizations.

**Phase II (Year 2)** – Expand the data set by at least 2x more, and including more countries and industries. Motivate a larger set of nations to contribute deeper data samples.

- The goal is to have enough data to make strong statistically sound correlations between industries, between countries and between different sizes of organizations – and cross-correlations like industries by country, and organization size by country.

**Phase III (Year 3)** – Expand the data set again by at least 2x more, and focus on hardening the predictive nature of the models by conducting additional research to "test" correlations. At this phase it the tie to large general economic data sets should be robust enough to be able to hand-off to other government organizations.

- The goal is to conduct enough research to show both strong statistical correlation – and causation between investments in HPC and the resulting ROI and innovation.
- In this phase the scenario testing should improve to be very robust and directly useful for making national policy decisions.
Please email: hpc@idc.com

Or check out: www.hpcuserforum.com
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• Senior technical project manager: John Daly, 508-935-4643, jdaly@idc.com
Questions to the Audience

• What are your ideas to quantify the benefit of HPC?
  o Publications count?
  o Grant money?

• What is the trade-off between hardware and human resources?
  o Can we argue for more human resources?

• Would you like to participate in the IDC initiative?

• ...
Potential Future Activities

Alternatives

- Don’t worry – be happy
  - In academia it is “just” tax money
  - In industry the customer will pay for it

- Participate by joining this SIG CBQ
  - Have a follow-up BoF at SC ’14 (if accepted)
  - Organize a workshop
  - Install a mailing list
As for Quantification...

Please fill in the evaluation form