On the Growth of Computational Services

Nicolas Boccard*

September 2011

Abstract

We update Nordhaus (2007)'s landmark study of computing power up to 2011. Using data about Apple Computers, we also go beyond the mere computing speed to produce a new index of the overall service afforded by laptops and tablets that takes into account durability and portability. We show that the yearly rate of improvement is about 65% instead of 40% when looking only at raw speed.

Keywords: Computer, Productivity, Hedonic Pricing
JEL codes: O30, O40

1 Long Term Evolution

In his landmark study of man's ability to perform mathematical operations, Nordhaus (2007) focuses on the performance of computers since the industrial revolution. During most of history, humans have only managed to develop mental calculation to support trade and accounting; there was virtually no technical progress to improve on those duties. Then, starting around 1850, mechanical calculators were invented allowing more complex tasks such as ballistic trajectories to be evaluated. Modern computing finally took off after WWII with electronic computers.

Figure 1 displays an *affordability* index of computing power since 1850 (cf. definition later on). The evolution is so staggering that a logarithmic scale must be used to keep the graphic readable.\(^1\) Since 1945, the index has increased at the average rate of 55% per year, whereas the economy grew at a mere 2% rate. This amounts to a duplication approximatively every 18 months, as predicted in some version of Moore law.

\(^*\)Departament d'Economia, Universitat de Girona, 17071 Girona, Spain. Financial support from Generalitat de Catalunya (Xarxa de referència d’R+D+I en Economia i Polítiques Públiques) and Ministerio de Educación y Ciencia (project SEJ2007-60671) are gratefully acknowledged. To allow reproduction of our results, we provide our sources.

\(^1\)Starting at the normalized zero value, each graduation represents a ten fold increase of the index.
Our work uses Nordhaus (2007)’s data appendix which contains information relative to the cost and performance of many historical computing machines as well as reporting complex benchmark tests for modern computers (up to 2006). The purely technological index is millions of computations per hour (MCH), normalized so that manual computation be unity.

To add a first economic dimension to the picture, Nordhaus looks at the cost of operating a computer i.e., accounts for the supply side. The yearly capital cost of computation is set at 20% of the machine real cost (10% for interest rate and 10% for depreciation). To obtain an hourly cost, 2000 hours of typical use is assumed. The labour cost per hour is the real hourly wage (nominal wage over GDP deflator) times the share of manpower needed for machine operation, typically full dedication for old ones and one percent for recent ones. Our CP$ index of computing power per $ is MCH divided by total hourly cost (summing both capital and labour components). Lastly, we account for the fact that per capita wealth has grown much since 1850; this is the demand side of the story. The index of computing power affordability, CPA, is then defined as the ratio of per capita real GDP to CP$.$\textsuperscript{2}$

As displayed on Figure 2, pure computing power (MCH) increased at an average rate of 3% per year during a century which is commensurate to general economic growth. However, the amount of computation afforded by one $ (CP$) remained almost stagnant because computing machines were expensive. Their unique character impeded taking advantage from scale economies. This in turn implies that our ability to afford computing services (CPA) increased at a positive but low rate (2%).

Regarding the recent era, we see on Figure 3 that the economic indicators overcame the technological one around 1990 when the large scale development of PCs drove cost down. Over this period, computing power grew at an average yearly rate of 37% (i.e.,

\textsuperscript{2} Nordhaus (2007) uses real wage which increased only half as much during the entire period
doubling in $\approx 26$ months) whereas the economic indices grew faster at 54% and 55% (i.e., doubling in $\approx 18$ months).

2 Recent Updates

The speed benchmark tests performed by the Standard Performance Evaluation Corporation (SPEC) allow to display the evolution of computing speed over the last decades in a more precise fashion. We select SPEC2000 as the basis and use the official conversions between the various historical measures. We sum the INT and FP scores to compute a single score per machine tested. Our SPEC index, for each month, is the mean of the upper quartile of the distribution of tests. Figure 4 displays all individual SPEC scores, together with the smoothed SPEC index.\(^3\) Based on the trend line, the speed benchmark grew at an average of 42% per year, over the period of study.

This recent data is also used to update Nordhaus (2007) using a linear fit of his scores over our raw SPEC index for the 1992-2006 period. We then scale the SPEC index over the 2007-2011 period to create new data points used in the figures of the previous section.

\(^3\)We scatter all the data points for a given month randomly within the month in order to draw a nicer picture.
3 Beyond Speed

In this section, we propose a new index going beyond mere computing power and cost adding the notions of endurance as well as transportability. We first define the *all-day performance* of a portable device as its total throughput i.e., the product of computing speed by battery duration (in hours). To factor in the disutility of carrying heavy equipment, we divide performance by weight to obtain a *productivity/kg*. We then divide by real cost (i.e., list-price expressed in 2011$) to get a *productivity/kg/$.

For estimation purposes, we focus on Apple Computers since there is a well recorded line of products from the first portable in 1989 until the iPad2 and MacBookAir of July 2011. We use the original price, the weight and battery life.\(^4\) Regarding performance (ability to perform tasks), we use historical benchmark tests from the specialized press converted into the *Geekbench* index whose series runs longest into the present. A variety of examples is displayed in Table 1 while the more synthetic information is revealed on Figure 5.

Over the two decades of study, raw speed increased at an average of 40% per year, productivity per kilo (dashed curve) at 49% per year while the cost adjusted one (plain

\(^4\)When available, a reviewer test is preferred to official values.
<table>
<thead>
<tr>
<th>Model</th>
<th>Year</th>
<th>Speed</th>
<th>Weight</th>
<th>Time</th>
<th>Price</th>
<th>Prod./kg</th>
<th>Prod./kg/$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mac Portable</td>
<td>1989</td>
<td>4</td>
<td>7.2</td>
<td>9h</td>
<td>10500</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>PowerBook</td>
<td>1995</td>
<td>35</td>
<td>2.2</td>
<td>3h</td>
<td>4850</td>
<td>10</td>
<td>22</td>
</tr>
<tr>
<td>Titanium G4</td>
<td>2001</td>
<td>245</td>
<td>2.4</td>
<td>4h</td>
<td>3240</td>
<td>102</td>
<td>728</td>
</tr>
<tr>
<td>MacBook</td>
<td>2004</td>
<td>731</td>
<td>2.1</td>
<td>5h</td>
<td>1752</td>
<td>357</td>
<td>2171</td>
</tr>
<tr>
<td>Intel MacBook</td>
<td>2006</td>
<td>2283</td>
<td>2.4</td>
<td>4h</td>
<td>1204</td>
<td>790</td>
<td>6983</td>
</tr>
<tr>
<td>MacBook Air</td>
<td>2009</td>
<td>2448</td>
<td>1.4</td>
<td>4h</td>
<td>1856</td>
<td>1469</td>
<td>8419</td>
</tr>
<tr>
<td>MB Unibody</td>
<td>2010</td>
<td>3358</td>
<td>2</td>
<td>7h</td>
<td>1225</td>
<td>2350</td>
<td>20412</td>
</tr>
<tr>
<td>MacBook Pro</td>
<td>2011</td>
<td>5917</td>
<td>2</td>
<td>7h</td>
<td>1200</td>
<td>4141</td>
<td>36687</td>
</tr>
<tr>
<td>Ipad 2</td>
<td>2011</td>
<td>750</td>
<td>0.6</td>
<td>10h</td>
<td>500</td>
<td>2537</td>
<td>53944</td>
</tr>
<tr>
<td>MacBook Air</td>
<td>2011</td>
<td>4552</td>
<td>1.1</td>
<td>5h</td>
<td>1000</td>
<td>6696</td>
<td>71183</td>
</tr>
</tbody>
</table>

Table 1: Apple Laptops Characteristics and Performance

curve) grew even faster at 66% per year. This result shows that the quality of the computing service afforded by portable computers (and now tablets) has increased much more than what mere speed would lead to believe thanks to improvements in endurance, weight and cost. For instance, the iPad’s low weight and long durability compensates for its low speed (wrt. a laptop) to produce a productivity per kilo in line with the trend. Taking into account its low price (wrt. an Apple laptop), this product even manages to achieve the best value for money.⁵

As recalled by Nordhaus (1998), the cost of living ought to measure the price evolution of the fundamental services we consume rather than looking solely at the prices of the inputs needed for production. Our finding may thus be used to improve the hedonic pricing of computer goods.

References


⁵As of August 2011, the new macbook air appear to achieve an even greater score if one is to believe Apple’s claim relative to speed.