Exposing Moore's Law as an Innovation Myth

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Abstract: Practitioners often claim that Moore's Law guided innovation efforts of the whole semiconductor industry for more than four decades. Providing a road map for long range planning Moore's Law has been said to determine research and development activities of microelectronic manufacturers and suppliers. However, the question whether Moore's forecast was in fact a self-fulfilling prophecy has never been empirically addressed. The present study aims to close this research gap applying Granger causality testing. Research findings clearly show that Moore's predictions do not Granger cause actual transistor counts exposing, thus, Moore's Law as a myth.

Keywords: Moore's Law, innovation, self-fulfilling prophecy, semiconductor industry.

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1. Introduction

In his seminal paper, Gordon Moore, the later co-founder of Intel Corp., described the regularity of technological progress in the semiconductor industry predicting that the numbers of transistors on a microprocessor will approximately double every 12 months [5]. However, Moore revised his prediction ten years later supposing a slower rate of progress for future decades where the number of transistors will double once every second year [6]. To his own surprise, the forecast he made in the mid 1970's worked well for more than four decades describing the technological development of the industry with astonishing accuracy. As van Lente and Rip stated "This prediction has come true so beautifully, that nowadays we speak of 'Moore's Law,' as if it were a law of Nature" [10, p. 206].

Moore's Law became very influential with time providing guidance for long range planning of the whole semiconductor industry, which has used it to set ambitious goals for research and development. Thus, many authors, including Moore himself, referred to the forecast as a shining example of a self-fulfilling prophecy [11]. To the best of my knowledge, however, the question of whether Moore's Law was, in truth, a self-fulfilling prophecy that guided innovation in the semiconductor industry for more than four decades has never been empirically addressed.

The aim of the present study is thus to test this proposition. In order to do so, I apply an empirical approach supposed by Granger to examine the causal effect of Moore's forecast on real technological developments in the semiconductor industry [2]. My research findings indicate no such causal relationship suggesting that Moore's Law has not causally influenced technological advances in the semiconductor industry. My results confirm other authors who theoretically argued in the same direction but provided no or just little empirical evidence for their arguments [9].
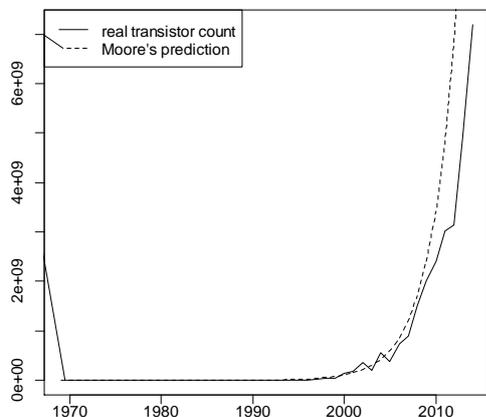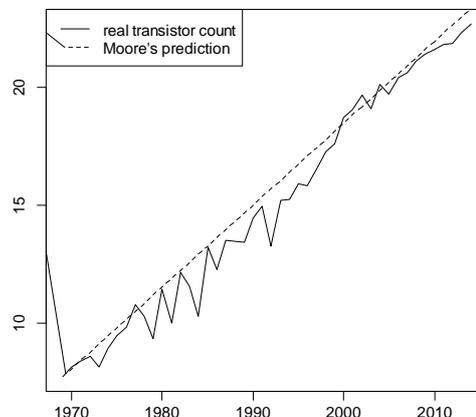

Figure 1: Transistor count over 45 years.

Table 1: Stationarity tests.

Testing procedure	Time series tested	
	Real transistor count	Moore's prediction

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Ljung-Box	LB=61.28 p<0.001	LB=71.10 p<0.001
augm. Dickey-Fuller	DF=−4.99 p<0.1	DF=−3.89 p<0.5
Kwiatkowski-Phillips-Schmidt-Shin	KPSS=0.04 p>0.1	KPSS=0.06 p>0.1

2. Method and Data

Before I present my empirical results, let me first briefly summarize the main idea of Granger's causality testing. Granger supposed that x cause y if lagged values of x predict current values of y in a forecast formed from lagged values of both x and y [2], [8]. Applying this idea to my research subject means that lagged forecasted transistor counts per chip should serve as bad predictors of the actual transistor counts if we suppose that Moore's Law was not a self-fulfilling prophecy.

To estimate the hypothesized relationship I use annual time series data from the Intel Corporation that is freely available on the corporate website. Data selected from the internet provides detailed information on microprocessors produced over more than four decades including dates of market introduction and the number of transistors per chip. Transistor count predicted by Moore was generated starting from 1971 under the assumption that the number of transistors would double every second year. Mathematically, Moore's Law is expressed as exponential growth:

$$Transistors_t = Transistors_{t=0} \cdot 2^{\frac{t}{T}} \qquad (1)$$

Where T represents the predicted doubling time (two years) and t denotes any year in the observation period from 1974 to 2015. The initial value for the calculation is set to 2,300 transistors per chip (corresponds to Intel 4004 introduced in 1974).

To perform Granger's causality test stationary time series are required. As shown in figure 2, both time series are, obviously, non-stationary processes. Thus, in order to achieve stationarity, I transformed the data using logarithm function and calculating first order differences. After data transformation several statistical tests were performed in order to check the validity of the stationarity assumption. All three testing procedures confirmed stationarity (table 1). Finally, Granger's causality test was performed with up to six lags.

3. Results

According to estimation results reported in table 2, my findings clearly suggest that the null hypothesis (Moore's prediction does not predict actual transistor counts) should not be rejected. Consequently, I conclude that Moore's predictions do not Granger cause actual transistor counts. In fact, Moore's Law should, thus, be not interpreted as a self-fulfilling prophecy.
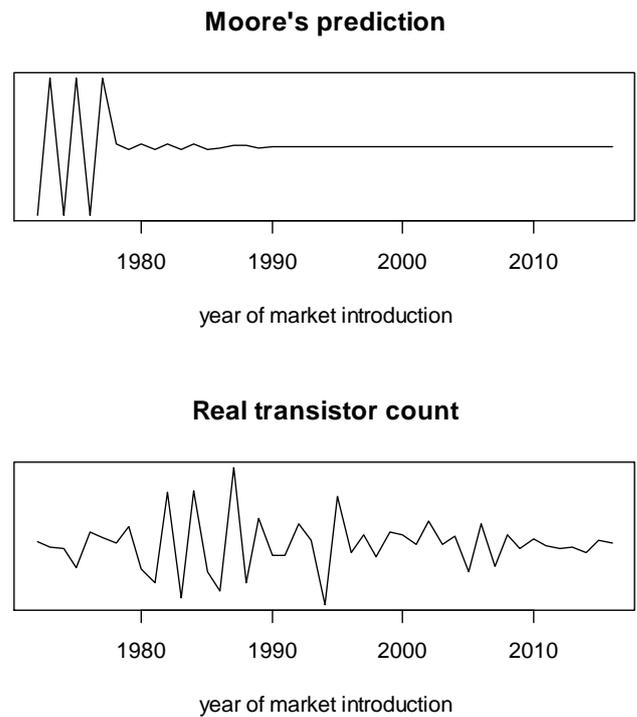
Moore's prediction

year of market introduction

Real transistor count

year of market introduction

Figure 2: Stationarity of time series.

4. Conclusion

Four decades after Moore's far-reaching forecast, the present study firstly investigated the causal relationship between predicted and actual transistor counts per chip. Findings of the study disprove the long-believed claim that Moore's Law constituted a self-fulfilling prophecy. The view that Moore's prediction channeled research and development efforts of the whole semiconductor industry belongs thus to the realm of business fairy tales, practitioners' musings and wishful thinking of big corporate players. Research findings of the study shed new light on our understanding of evolution processes in the semiconductor industry pointing out the necessity for new research.

Table 2: Granger causality testing.

	Does Moore's prediction Granger cause actual transistor counts? $H_0 : \beta_0 = ... = \beta_L = 0$					
Number of lags (L):	1	2	3	4	5	6
F-Statistic	0.019	0.635	0.469	2.280	1.678	1.812
p-value	0.891	0.535	0.706	0.082	0.172	0.136

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