

## Long-Term Productivity Mechanisms of the Semiconductor Industry

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For nearly half a century, the semiconductor industry has been growing on an upward revenue trend of ~16%. A small set of business and technology relationships can characterize this remarkable result. Figure 1 shows how revenue, capital investment, output (measured in transistors) are related to the key metric of functional cost or “productivity” (\$/transistor). This falling functional cost is assumed to be responsible for the continuously growing demand for electronics and semiconductor products.

Just a few key factors drive the reduction in functional cost. The foremost effect is the ability to decrease the size of the smallest feature so that more transistors can be built per area of silicon ( $\text{Tx}/\text{cm}^2$ ). The secondary and necessary adjunct effect is the relative stability of the cost to process silicon ( $\$/\text{cm}^2$ ). The rise in density is almost completely attributed to advances in photolithography, with necessary tracking improvements in deposition, etch, and measurement. There is a smaller component of density improvement that obtains from design, whereby inventive configuration and layout of device elements has allowed the space required per function to drop.

The constancy of area cost can be analyzed according to the historical evolution of its key subcomponents. The long-standing major contributor to area cost is equipment capital cost (in the form of nominally 5-year depreciation). This typically represents about 35-40% of the cost per  $\text{cm}^2$ . The remaining key items (for a given yield) are consumables, product and non-product substrates, maintenance, floor space, and personnel.

In the early years of the industry (through the 1960’s and 1970’s), yield increases were a key mechanism by which productivity improved. By the mid-70’s, yields in volume production had reach diminishing returns, and today yield is a baseline requirement for productivity, not a contributor to productivity improvement. Wafer size changes have also been regular productivity enhancements over the years. When the wafer area increases by  $\sim 2\times$ , but the cost of the new tool set increases by only 30-40%, the cost per area decreases by 30-50%, an annualized improvement of about  $\sim 4\%$ .

In the future, additional productivity enhancements will be required to keep the functional cost dropping at historical rates. Some of the existing mechanisms may not be effective in the future. Improvements in yield or equipment utilization and efficiency are capped at 100%, so they contribute with diminishing returns; the transition to the next larger wafer size is a formidable, multi-billion dollar, multi-year exercise; and today’s design tools are in

no way keeping up with design complexity and may reduce the rate of innovative density improvement.

Using the *International Technology Roadmap for Semiconductors* (ITRS) and an industry economic model developed at International SEMATECH, we will assess the costs and benefits of the new and “traditional” productivity enhancers anticipated over the next decade. These include non-planar devices and 3-D integration and scaling for increased density, the cost impact of rapidly shifting lithography generations, and possible alternatives to a 450mm wafer generation.

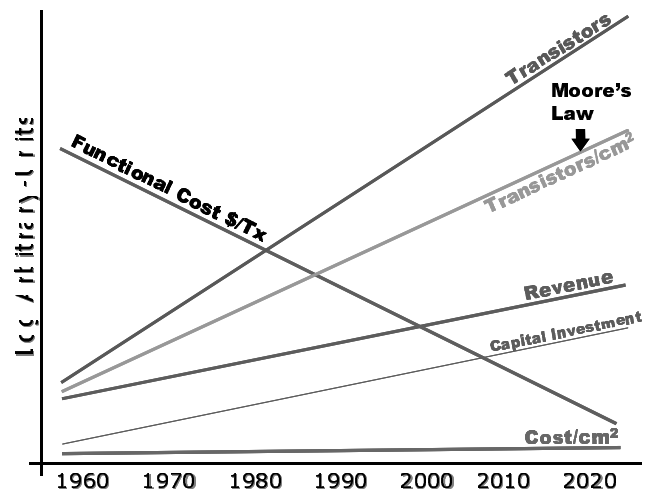


Fig. 1. Functional form of key semiconductor industry economic/business trends.