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Economic and Business Dimensions

The Value of Microprocessor Designs

Applying a centuries-old technique to modern cost estimation.

Over the years the leading microprocessor company, Intel, has introduced a steady stream of new microprocessor designs: the 286, 386, 486, Pentium, Pentium II, Pentium III, Pentium 4, and more recently the Multicore design. In the microprocessor industry these designs are called *microarchitectures*. If there was a market for microarchitectures what would each design sell for? Our research addresses that modern question using economic insights developed almost two centuries ago.

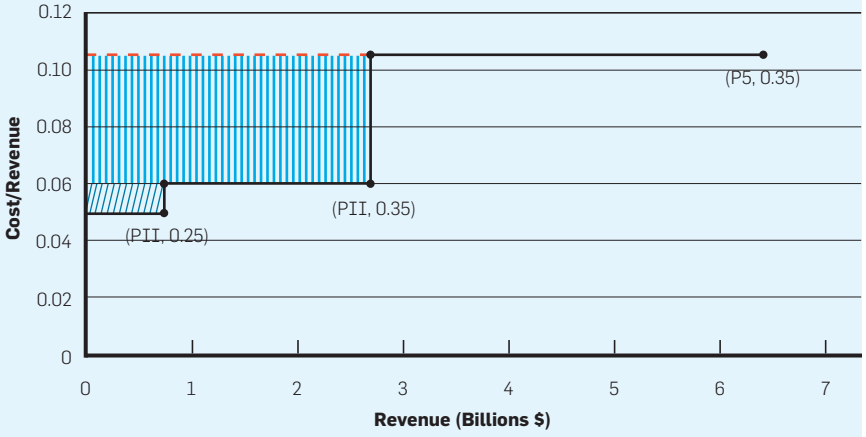
Why estimate the value of these designs? This type of calculation can inform many aspects of firm strategy and valuation. Many companies develop new designs and increasingly outsource the manufacturing of the products. For example, fabless companies like Qualcomm and Broadcomm design chips and do none of their own manufacturing. Foundries do it for them on contract. The value of the fabless firms depends predominantly on the value of designs.

Many factors complicate any attempt to estimate the value of intellectual property associated with such product designs. In microprocessors for instance, consumers are not willing to pay for a new design per se, but for the increase in computing power that comes with a new design.

The classical economist, David Ricardo, had the key insight in 1817.[2] Ricardo asked how much would be the rent to a unit of fertile land (say close to a river). Ricardo reasoned that producing a pound of corn in the fertile land is less costly to a farmer than producing a pound on marginal land (the worst land being cultivated, say in the hills). The fertile land requires less effort to achieve the same output. The rent for the fertile land arises from the difference between the labor cost of producing the same quantity of crop on the fertile land and on the marginal land. Charge the farmer a rent higher than this maximum, and the farmer would prefer to move out and start cultivating the marginal land.

Ricardo's logic still applies today, and can help estimate the rent to a new microprocessor design at any point in time. Think of a new design as analogous to fertile land and an old design as the marginal land. A microprocessor made with a new design can compute faster and hence sells for a higher price. To get the same revenue from selling microprocessors with older designs, Intel would need to sell more of the older microprocessors, something that involves more labor cost than making one microprocessor with the new design. The rent for the new design, therefore, is the difference between the cost of producing a dollar of revenue with the new design and the cost using the old

Cost/revenue ratios for three Intel processors.



Estimate of the total value of the Intel design or process technology.

Design	Cost Savings*	Process Technology	Cost Savings*
486	0.26	0.80	0.96
Pentium	2.74	0.60	1.18
Pentium II	0.82	0.35	5.16
Pentium III	4.30	0.25	1.64
Pentium-M	1.35	0.18	3.00
Pentium 4	0.01	0.13	14.40
CORE	2.63	0.09	5.01
		0.065	2.08
TOTAL	11.85	TOTAL	33.43

*Cost savings in billions of dollars.

design in a given time period. Adding up all such rent across the lifetime of a specific design provides an estimate of the value of the design to Intel.

It is not quite that simple in practice, of course. Increases in computing power can come from factors other than a new design. The decreasing size of transistors used in microprocessors is the leading example. Advances in semiconductor process technology have steadily driven down transistor sizes from three microns (where a micron is a millionth of a meter) in the original 8086 made by Intel to around 0.022 microns in the latest chip. These smaller transistors—by themselves—lead to greater computing power, without any improvements in designs. In other words, a proper estimate must separate the value provided to Intel by new designs from the value provided by the technological transitions to smaller transistors.

To summarize, Ricardo's logic still applies. It can be applied to the measurement of rent to a new microprocessor design at any point in time. A new microprocessor can be defined as a pair of attributes: the design it uses and the semiconductor process technology it was made with. The rent to the combination of design and process technology used in a new microprocessor is the cost savings the new microprocessor provides over the oldest one currently in use. If the new microprocessor uses the same process technology as the oldest one currently in use, then the difference in the cost of production is the rent to the design. On the other hand, if the new microprocessor uses the same design as the oldest one currently in use, the difference in cost of production is the rent to the process technology.

The accompanying figure illustrates the approach, using data from Intel's production for the third quarter of 1997. There were two designs in operation in the quarter, Pentium (P5) and Pentium II (PII). There were process technologies, 0.35 microns and 0.25 microns. There were three microprocessor vintages in production, (P5, 0.35), (PII, 0.35), and (PII, 0.25). The *y*-axis shows the average cost/average price of microprocessors of each vintage. The *x*-axis shows the total revenue obtained from each vintage.

What is the message of the figure? The (P5, 0.35) vintage of microprocessors were the oldest ones, and had a high cost/revenue ratio. Microprocessors produced with the same process technology, but with a new design (PII) had a lower cost/price ratio. The latest microprocessors featuring a new design (PII) and a new process technology (0.25) had the lowest cost/price ratio among the three vintages. The vertical distance between the top and the second horizontal lines is the cost saving provided by the new design PII over the old design P5, for each dollar of revenue that Intel obtained by selling the chips that used PII design. Hence the total rent to PII design during the quarter is the area of the rectangle shaded with vertical lines. Similarly, the area of the rectangle shaded with diagonal lines is the rent to 0.25-micron process technology during the quarter.

An estimate of the total value of the design or process technology to Intel comes from constructing similar diagrams for all the quarters in which a design or process technology was in use and by adding these up. The accompanying table shows the estimates we obtained in our study.[1]

The cost savings from new design is in many billions of U.S. dollars. One can see from the table that Intel's savings from new process technologies was almost three times the savings from new microprocessor designs, indicating the relative importance of new manufacturing technology transitions to Intel.

The table also includes information about the value of specific designs. The Pentium 4 design provided very little value to Intel. This is not surprising due to its problems with overheating, which forced Intel to move to the new multicore designs. The Pentium III was the most valuable design for Intel, reflecting perhaps the high price that new designs were able to command at the height of the Internet boom of the late 1990s. In that period, Intel used the 0.13 manufacturing technology, again the one that we estimated to have provided most value to Intel.

It should be noted that these values are calculated ex-post, after the microprocessors that used these designs were sold on the market. This method is not appropriate for forecasting value prior to any market experience, an important precaution in interpreting these figures. Intel probably spent the most on developing the Pentium 4 among all its designs, an investment that did not pan out for Intel.

Overall, these calculations provide a rough estimate of the value to Intel of intellectual property embedded in new designs. Ricardo's centuries-old wisdom on land rents turns out to be insightful for valuing intangible assets.

References

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