Is Bigger Better?

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Abstract

Increased investment costs for larger substrate factories require breakthrough efficiencies and the capture of price premiums. Otherwise, their profit indicators will fall below those of prior plant investments. Market factors inhibit the continued expansion of monitor size and resolution, so a television market must be developed if substrate size increases will remain profitable, long term.

The race upwards

One could say that the first decade of mass-production was a quest for efficient substrate sizes. TFT manufacturers were in a race to achieve profitable operations while making ever-larger screen sizes. Early attempts to achieve reasonable operation efficiency targeted four panels per substrate. Meanwhile, notebook PC users demanded ever-larger screens and manufacturers increased panel sizes with each new factory generation. Later in the decade, manufacturers were able to fabricate six panels per substrate while increasing screen sizes to 15 inches diagonal. The present decade has brought a continuation of the race as manufacturers struggle to increase screen sizes for PC monitor applications.

If one curve fits a Gompertz function (S-curve) to the dates of mass-production starts of new-generation substrate factories since 1990, the quarterly growth rate of substrate area is 4%. That equates to an annual area growth rate of nearly 17%. See figure 1.

The race downwards

The quest for efficiency was necessary to achieve profits while increasing shipments because panel demand is elastic relative to price. Reliable, weighted average selling prices for notebook panels are not available for the early years but DisplaySearch provides consistent data for the 14.1-inch XGA panel that has become the most widely deployed notebook screen type. Based on data for this benchmark product since 1997, selling prices have declined 5.5% per quarter. See figure 2.

The TFT industry has often been compared to the DRAM industry, as both are subject to periodic oversupply caused by competitive investments. Looking at the quarterly (volume-weighted) price movement of 14.1-inch panels, one can see significant fluctuation about the trend line. In the oversupply situation of 1998, prices fell 25% below the trend line in 3Q98. In the subsequent undersupply situation, prices rose 29% above the trend line in 2Q00. At present, the panel price is again 29% below the trend line and prices are expected to strengthen as the rate of capacity expansion slows. One can now plot more than a full supply-demand cycle for 14.1 XGA products. The apparent business cycle is eleven quarters, but boom and bust phases are not necessarily symmetrical.

Price oscillation around the trend line and product diversity has made it difficult to characterize price trends. Managers and planners have found it difficult to predict price relationships between products, so funding fabrication plants has been a gamble. Fortunately, a method for characterizing prices of various products was presented by the author at the Flat Panel Display Conference sponsored by DisplaySearch in March of 2001. Called the kilo-pixel-inch or kpi for short, the metric factors the screen area and diagonal pixel count of each panel type. The area factor (equation 1) simply computes the screen (display) area in square inches. The pixel factor (equation 2) calculates the number of pixels represented by the screen diagonal. In essence, this factor is the product of ppi and the screen size. It provides a weighting factor for the resolution of the screen because each diagonal pixel is the intersection of a row and a RGB column. Multiplying the area and pixel factors (equation 3) produces the simplified formula. Dividing by 1000 yields the kpi factor, which is useful for comparing the mature market value of various panels.

(1) Diagonal * COS(ATAN(V_pixels/H_pixels)) * Diagonal * SIN(ATAN(V_pixels/H_pixels))

(2) Diagonal * V_pixels / (Diagonal * SIN(ATAN(V_pixels/H_pixels)))

(3) (Diagonal ^ 2) * V_pixels * COS(ATAN(V_pixels/H_pixels))

The race for premiums

The theory behind the kpi metric is that panel prices tend toward equivalence on a dollar per kpi basis as the products mature. A look at pricing history since 1997 shows that $/kpi equivalence is indeed the long-term trend. This makes sense in

that customers value both screen size and pixel (or information) density. On the other hand, for newly introduced screen sizes, TFT makers can obtain a premium. A price premium over the benchmark kpi price can be justified for a time because makers face increased yield risk and users face increased information space. After a time, yields improve, prices decline and shipments increase. The formerly premium product becomes a commodity governed by kpi-price dynamics.

History suggests that kpi-price premiums are 10% for screens one step above the benchmark, 20% for screens two steps above and as high as 35% for screens three steps above. In all observed cases, the premiums decline to zero in three years. In the case of screens one-step above the benchmark, the premium might last only four or five quarters.

The race for profits

The inevitable march towards commodity pricing makes the acquisition of premium prices a driving force for new-generation substrate factories. Construction of larger substrate factories should be timed so that they can fabricate panels several steps larger than commodity sizes for the first few years of operation. Furthermore, mass-production starts should begin when the business cycle turns toward undersupply and commodity prices begin to rise above the trend line. However, even if successful, makers might not obtain the desired profit level from new factories if the new factories are not more productive than older ones.

If one combines the price decline trend of 5.5% per quarter with the area growth trend of 4% per quarter, one finds that the difference reaches unity in eleven (11) quarters, the length of the business cycle. From this, one can calculate the efficiency gain required to obtain unity in a shorter time. TFT makers generally aim to bring-up a new factory every two years in order to capture the up swing in prices and to take a leading position in premium products. The efficiency improvement required to reach unity returns on investment is approximately 3% per quarter or 26.6% over eight quarters. See figure 3. The ability to capture higher margins through premium products can reduce the required efficiency gain, however.

The race for efficiency

Experience suggests that new-generation factories have to be about 20% more efficient than previous generation plants if TFT makers are to maintain a leadership position. The gains in efficiency can be achieved through incremental and breakthrough improvements. Note that reductions in material purchasing cost generally affect old and new plants so that such cost savings do not improve the operating efficiency of new factories relative to older ones. Furthermore, some forms of incremental improvement such as practices or methods can also be applied to older factories (to some degree, at least). Therefore, TFT makers must achieve breakthrough improvements if the profitability of new-generation factories is to meet or exceed that of previous investments.

In a presentation at the FineTech Japan earlier this year, D.H. Ku of LG.Philips LCD explained the company's approach to improving efficiency of its fifth-generation factory designated P5. The new plant will use a 1000 mm by 1200 mm substrate with a process area twice that of the earlier generation P3, which started mass production in 2000. In brief, LG.Philips LCD targets four breakthroughs in equipment productivity and process efficiency.

- Cell Shop: perhaps the most significant improvement comes from development of a new tool and process for filling large cells. The method of vacuum alignment with liquid crystal (VALC) reduces the time for filling a 18.1-inch cell from 39 hours to 14 hours. VALC reduces the number of systems required from 18 to 15, eliminating nine operators. The decreased turn-around time allows more efficient line balancing and creates new business opportunities for large panel products.
- Color-filter Shop: a combination of a double-developer line and acrylic-based photoresist promise to halve the floor space required to support the flow.
- TFT Shop: an air-bearing conveyor system coupled with a compact cleaning system and deposition cluster reduces floor space by 30% and handling steps by three.
- Process: a reduction in masks from five to four for mainstream products will be applied. The process combines activation and Source/Drain metal deposition through continuous etching. A 9% reduction of space is achieved by eliminating one photo aligner and stripper.

Is bigger better?

Given the foregoing discussion, one can see that maintaining or improving the profit indicator (discounted cash flow divided by investment

capital) of new fabrication plants depends both on risky breakthroughs and price premiums for a significant portion of the product allocation. Looking at the S-curve predictor for 4% compound growth in substrate area per quarter, there is little reason to doubt that larger substrates will come into production in the coming years. However, there is reason to question if premium products will be fabricated on them.

Up to this point in TFT history, panel makers have found ready markets for larger, higher pixel screens. Some market factors now appear to inhibit the steady growth of kpi demand, however. For one, operating system and application software limitations reduce the legibility of system text and icons at higher pixel densities. Similarly, desktop computers do not support digital monitor interfaces for UXGA or higher resolution formats. Without increased pixel counts, there will be little demand for screens larger than 20 inches. If such inhibitors persist for the next several years, it will become increasingly difficult for sixth generation factories to achieve profit indicators commensurate with past generations. Even high-risk efficiency breakthroughs might not be sufficient, as discussed above.

Development of a TFT television market seems to be necessary for continued expansion of substrate size and preservation of current profit indicators (which range from 1.25 to 1.75). Even assuming that PDP products reach consumer price points, TFT-based televisions could offer HDTV resolution and portability in the 20~30 range. It could even be possible to fabricate six 34-inch HDTV panels on a substrate by 2006, given the projected area growth.

So, the TFT industry is at a crossroads. Is bigger better? Yes, for the near term. For the long term, the industry must develop both efficient product and distribution networks to create consumer demand for TFT televisions. Otherwise, the rate of substrate growth will slow as TFT makers find ways to specialize smaller or existing substrate sizes for higher levels of value-added fabrication.

Figure 1: Gompertz curve fitting of the growth in substrate area

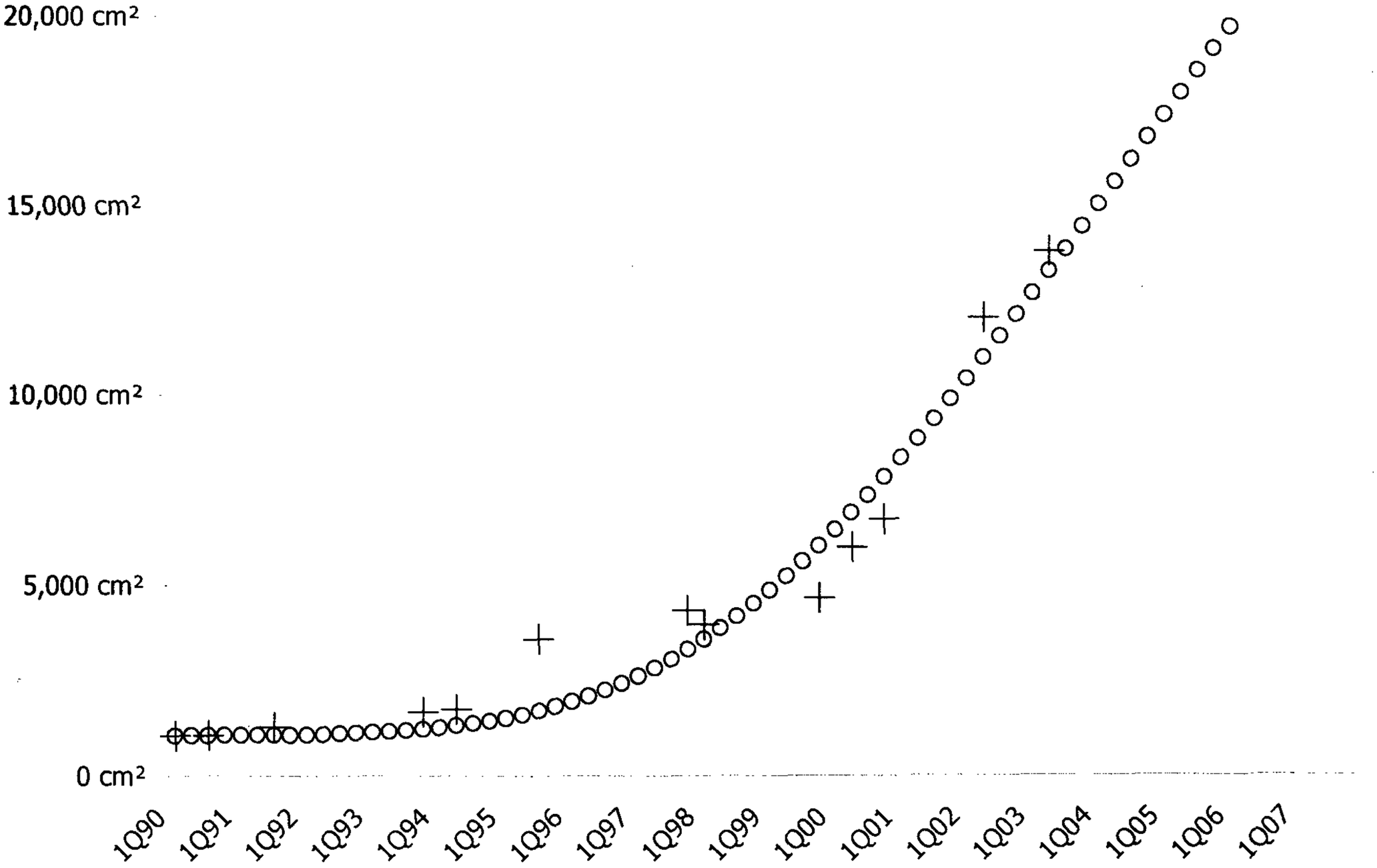


Figure 2: Oscillation of 14.1-inch XGA prices about the trend line

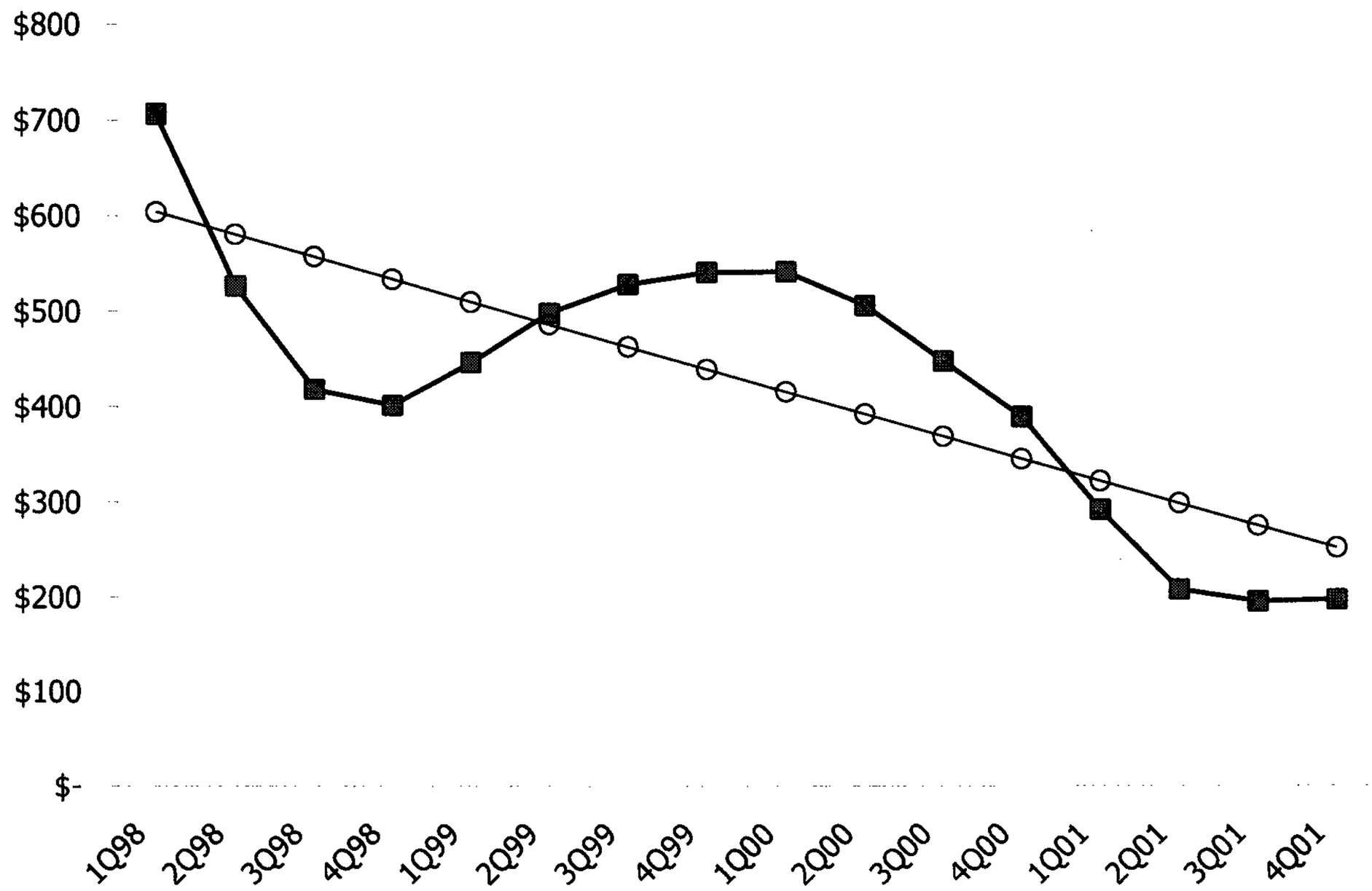
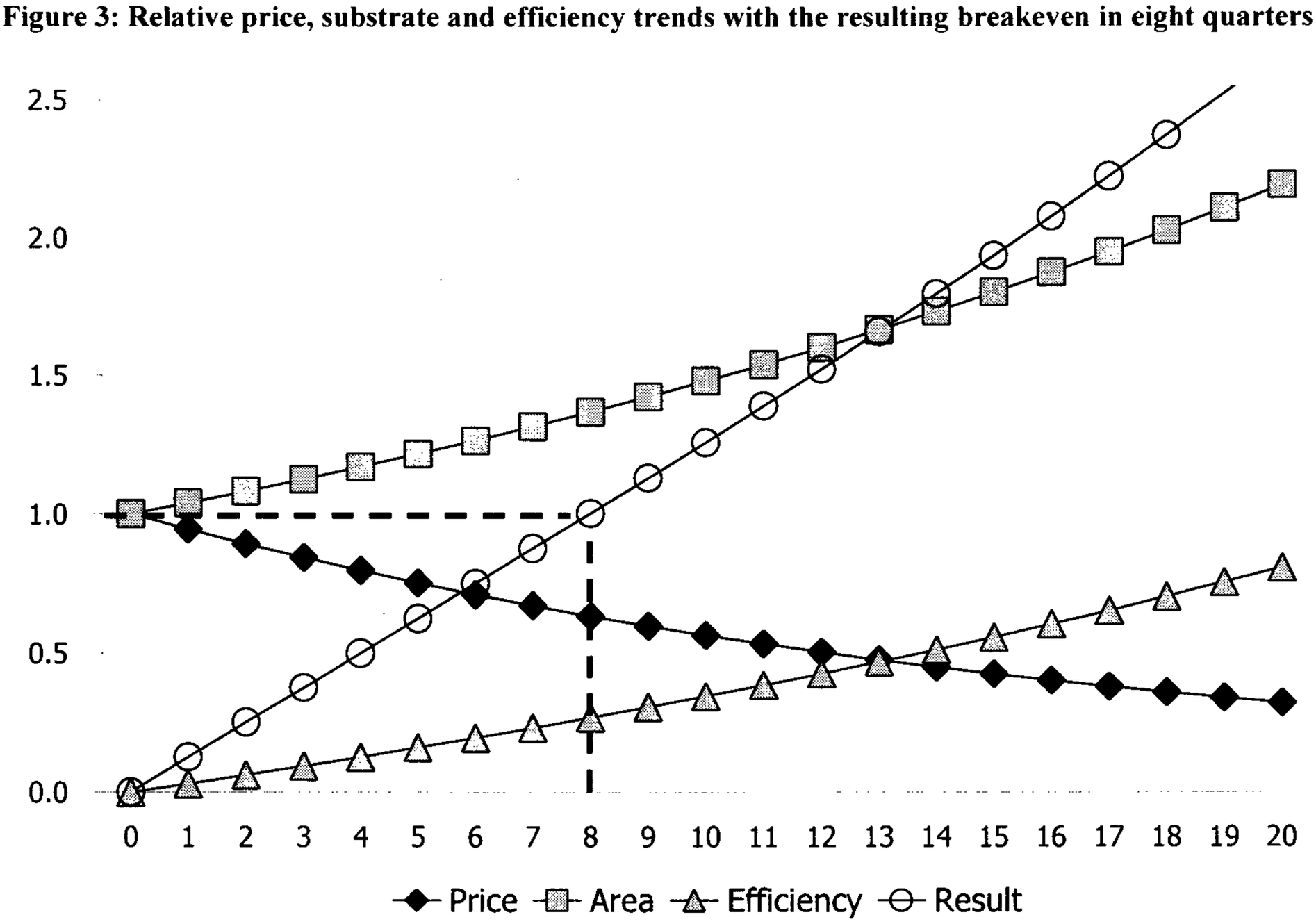


Figure 3: Relative price, substrate and efficiency trends with the resulting breakeven in eight quarters



LG.PHILIPS LCD

Is Bigger Better?

A look at economic factors that affect next-generation factory profit indicators

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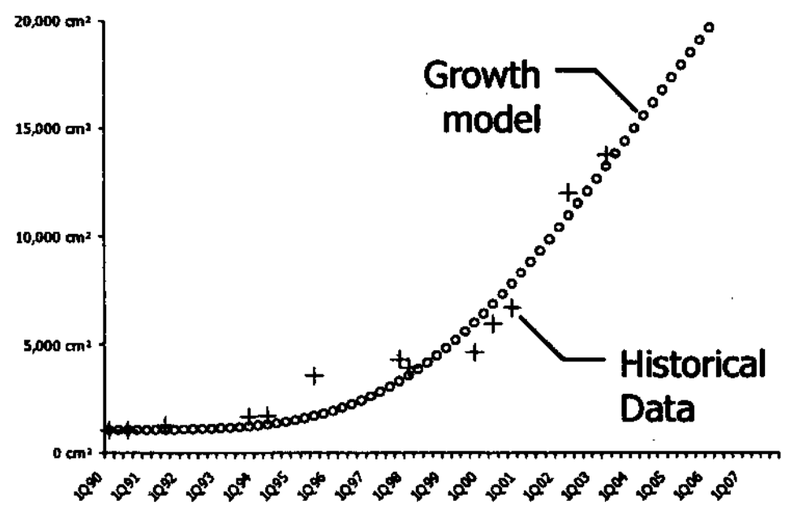
In the 1990s, TFT makers increased substrate sizes rapidly in pursuit of large-panel markets.

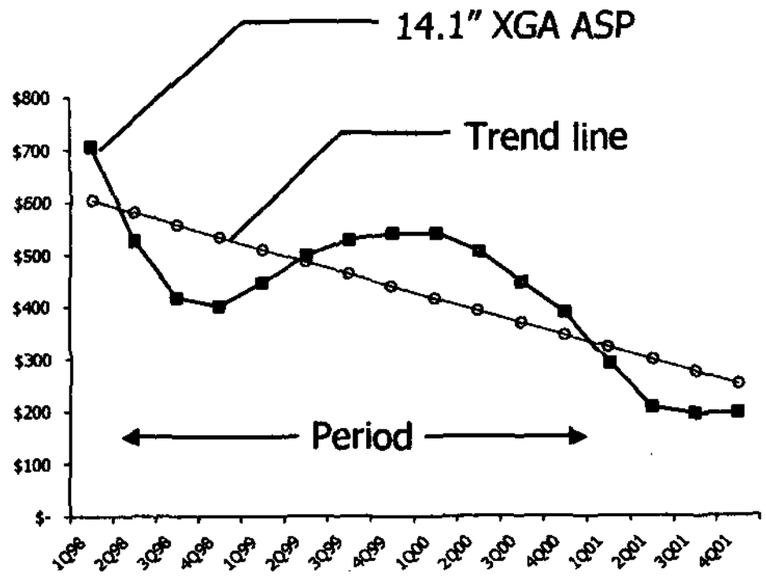
- Fitting a Gompertz (S-curve) function to the dates of new-generation production starts, we find area grew 4% a quarter.
- The growth projection indicates that large HDTV panels can be fabricated six per substrate by 2006.
- The question is whether market forces will allow development of TFT TV demand or will they constrain TFT makers' ability to capture premium prices in the future.



Source: DisplaySearch and author's analysis

While substrate sizes increased, large panel prices decreased.

- Volume-weighted average module prices for 14.1-inch XGA notebook displays show two factors at work.
  - Long-term price erosion at 5.5% per quarter.
  - Short-term oscillation about the trend line due to the supply-demand cycle.
- The eleven-quarter business cycle can be seen clearly in the price movement.
  - In the oversupply situation of 1998, prices fell 25% below the trend line.
  - Prices rose 29% above the trend line in the subsequent undersupply situation.
  - In the present oversupply situation, prices again fell 29% against the trend.



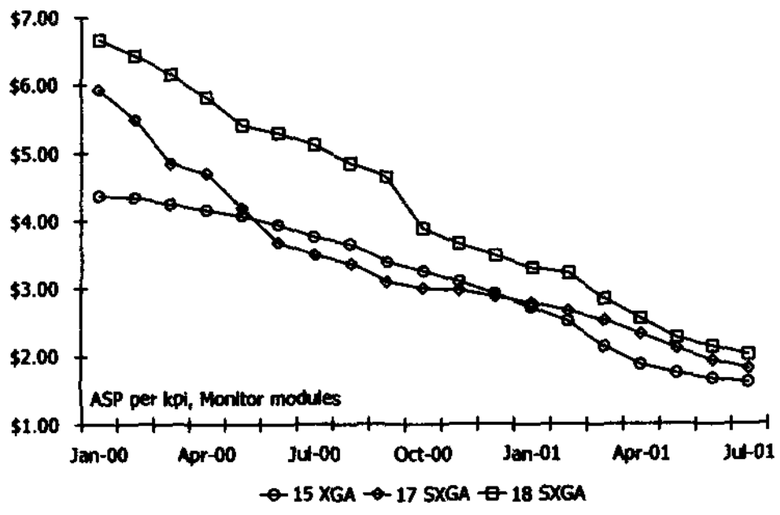
Source: DisplaySearch and author's analysis

Despite increasing product diversity, prices tend to converge on a kilo-pixel-inch basis.

- Mature market price relationships tend to converge based on two physical properties of the display panel.
  - Price per square inch
  - Price per pixel
- These factors can be expressed by the formula for a kilo pixel-inch:

  $D^2 * \cos(\text{atan}(Vpix/Hpix)) * Vpix / 10^3$

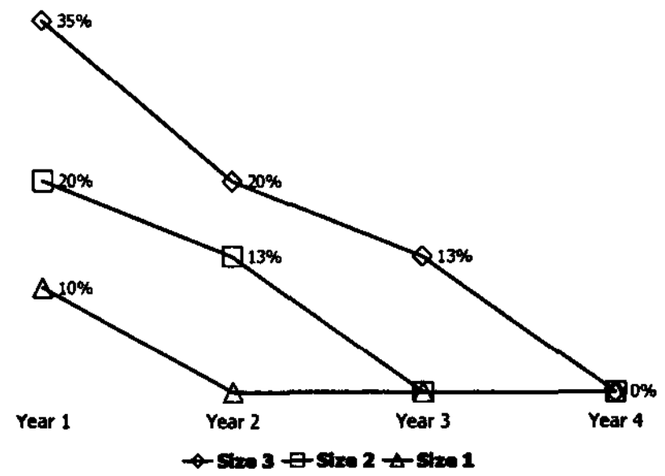
- It then becomes a simple task to predict the future price of any large panel relative to a commodity such as a 15" XGA panel.
- Given a price forecast, manufacturers can set production cost targets and estimate the return on their investment.



Source: DisplaySearch and author's analysis

Capturing premium prices for advanced panels is a major profit contributor for new-generation TFT factories.

- New-generation factories generally enable TFT makers to fabricate four or six premium products per substrate.
- Premiums decline over time, but they provide added margins to offset higher costs of new-generation factories:
  - Initial capital costs;
  - Initial yield losses.
- By the time a new factory has stabilized, most premium-panel prices have fallen to their $/kpi commodity level.

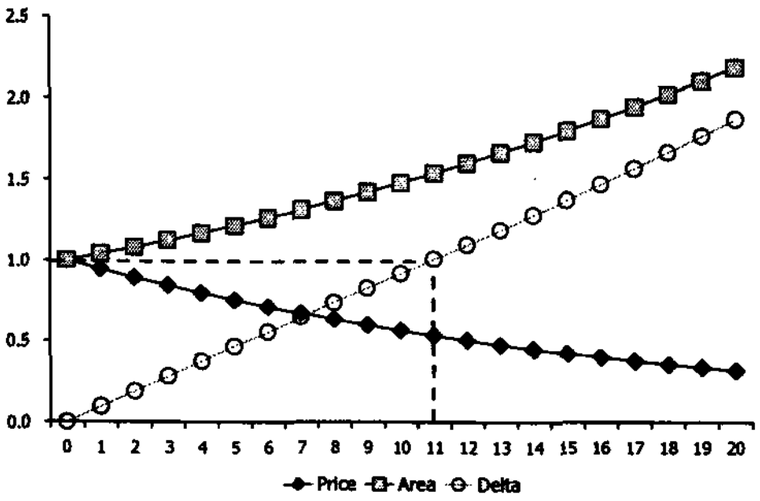


Source: DisplaySearch and author's analysis

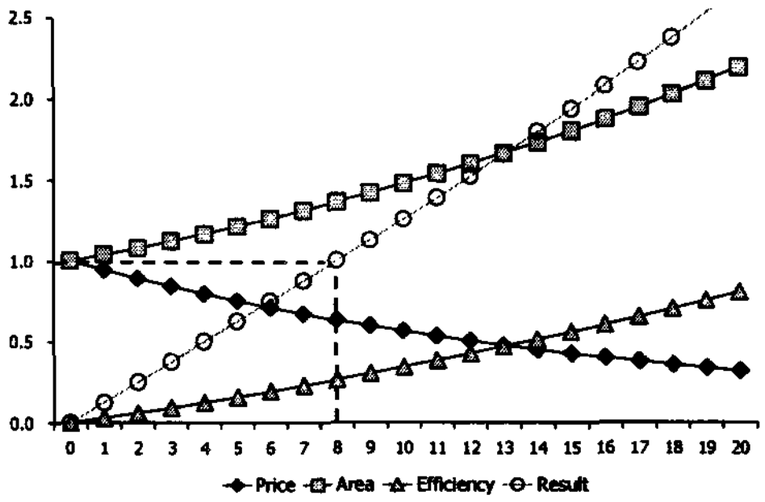
Evaluating all the factors, one can see that increased factory efficiency is required to obtain the same profit indicators as in the past.

- Prices fall 5.5% per quarter but substrate area increases only 4%. It takes a complete business cycle to regain unity but next-generation factory investment is greater.
- Regaining unity in eight quarters (ideal for capturing price premiums and the business cycle up-swing) requires factory efficiency gains of 3% per quarter; 27% over two years.

Delta calculation of price growth and area growth



Calculation of the necessary efficiency improvement



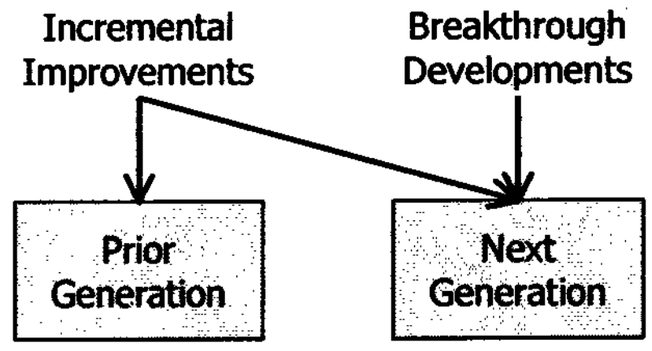
Source: DisplaySearch and author's analysis

Assuming price premium capture, perhaps only 20% factory efficiency improvement is required.

- Efficiency gains can come from two sources: incremental improvements or breakthrough developments.
  - Some incremental improvements can be applied to new and old factories, so these do not necessarily maintain or improve the profit indicator of new plants.
  - Similarly, material cost reductions generally improve all operations.
  - Breakthrough developments are therefore necessary for achieving significant gains.
- LG.Philips LCD's new P4 factory will use 1000 mm by 1200 mm substrates.
  - Twice the area size of P3, which began operation last year.
  - Four breakthrough developments are planned.

$$\text{Profit Indicator} = \frac{\text{DCF}}{\text{Capital Invested}}$$

The discounted cash flow from new-generation plants must increase in proportion to their larger capital costs despite steady price erosion.



Breakthroughs in tools and processes are necessary to preserve the historic profit indicators in the 1.25 to 1.75 range.

1. Vacuum alignment with liquid crystal (VALC) is a new cell shop process and tool set that reduces filling time for 18.1-inch cells from 39 to 14 hours.
   - Tool reduction from 18 to 15 sets
   - Operator reduction of three per shift
2. Double-developer line and acrylic-based photo-resist in the color filter shop reduce floor space by 50%.
3. Increased integration of developers and cleaners with an air-bearing conveyor reduces floor space by 30% and eliminates three cassette handling steps.
4. Mask reduction through self-aligned wells and source-drain metals eliminates the need for one photo aligner and stripper set, thereby adding 9% more floor space for other processes.

Source: DisplaySearch and author's analysis

The question is: will market dynamics offer premium price opportunities in the future, or will profit indicators depend on breakthroughs?

- PC market dynamics are beginning to inhibit the continued expansion of kpi.
  - Software does not support high ppi text or icons.
  - Hardware does not support high resolution digital interfaces.
- If premium monitor product opportunities decrease over time, then TFT TV market demand must be developed to provide continued premiums for new-generation factory investments.
  - Production challenges: array impedance and video response.
  - Distribution challenges: integrator-dealer markups and PDP competition.
- Otherwise, the profit indicators of next-generation factories will begin to fall relative to prior investments.
  - This is a normal development in maturing industries.
  - Eventually, TFT makers might optimize new plants for serving specific markets.
    - Front-end/backend balance
    - Increased forward integration

Source: DisplaySearch and author's analysis