Semiconductor Industry Dynamics.
An investigation for a General Pattern of Evolution

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Theme A: Industrial and Market Dynacmis

A central question in the field of industrial organisation is how innovation constrains the evolution of concentration rate over time. The link between innovation and market structure has been widely described by the literature (Dasgputa and Stiglitz, 1980, Nelson and Winter, 1982, Jovanovic and Mac Donald, 1994, Klepper, 1996, Sutton, 1998). One of the challenges emphasised by empirical analysts (e.g. Pavitt, 1984, Pavitt et al. 1987, Geroski, 1990) is to explain strong sectoral differences and non linear relations between firm size and innovation intensity that limit traditional arguments such as scale effects or first mover advantage. Neo-Schumpeterian tradition (Nelson and Winter, 1982, Malerba and Orsenigo, 1993, 1996, Dosi et al. 1995) argue that innovation intensity is a central determinant of market structure. More precisely, it is the nature of the technological environment that determines specific regimes of innovation and the subsequent level of competition.

Another stream of research considers that competition intensity evolves along with product maturation. This work originates in the findings of a systematic process of shakeout at the early stage of products' mature phase (Gort and Klepper, 1982, Klepper and Graddy, 1980, Klepper and Miller, 1995). Two different propositions try to explain shakeouts (cf. Klepper and Simons, 1999).

A first class of approaches links shakeouts with an exogenous event that changes competition conditions and results in a change of firms' survival probability. For example, Abernathy and Utterback (1975, 1978), Utterback and Suarez (1993), Klepper and Graddy (1990) consider that after an experimentation phase characterised by high opportunism and intense design competition giving rise to product innovations, a dominant design emerges providing a competitive advantage to earlier adopters that can invest in process innovation. Late adopters or design competitors, who do not enjoy scale economies and learning effects, become less profitable and eventually exit.

A second class is proposed by Jovanovic and MacDonald (1994). Their model holds in a partial equilibrium environment where an exogenous radical innovation affects the equilibrium state of the industry by opening up new innovative opportunities. Firms that succeed in innovating enjoy lower unit costs than those firms that keep the older technology and grow faster to the optimal size. This provokes exit of those firms that failed to adopt the new technology accentuating first mover advantage and the shake out process.

Klepper and Simons (2000) convincingly show that, while challenging, Jovanovic and MacDonald's model fails to explain empirical evidence. Dominant design theory cannot provide a general framework either since many industries experiencing shakeouts happen to have no dominant design, so the choice between product innovation and process innovation is

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not exclusive (Klepper and Simons, 1993). Rather they propose that industry life cycle is endogenously determined by firms' strategic behaviour. Indeed Kleeper (1996) develops a model that does not postulate any exogenous event. The author considers that shakeout is essentially induced by the endogenous evolution of expected return to product R&D and to process R&D. He ascribes shakeout to the natural (convex) learning curve phenomenon coupling cost reduction and the level of output produced. Firms are endowed with different capabilities (randomly allocated). At each period they choose to allocate their R&D resources between product and process innovation regarding their expected pay-off. Product innovation attracts new customers willing to pay more for the new product and keep faithful to this product that becomes a standard product in the following periods, increasing standard product market size. As unit cost reduces with size, there is a threshold after which earlier entrants have more incentive to engage in a process innovation than in a product innovation. As industry evolves and the market grows, the unit cost of the standard product, benefiting from process innovation, tend to drop so that new products only attract an ever smaller fringe of the market. Eventually, firms that have not achieved the critical size exit and the industry achieves its maturity phase resulting in a tight oligopoly.

The aim of the paper is to show that Klepper's industry life cycle model is a particular case of a broader pattern of evolution. Relying on the study of the semiconductor industry, we show that product differentiation in growing markets can give rise to different dynamics regarding first the intensity of knowledge obsolescence and second the potential of new outlets of new products.

More precisely, while products experience the maturation process, as described by Klepper (1996), product innovation gives rise to new technological opportunities dedicated to potential new markets, particularly when competing technological trajectories can be developed. Following the arbitrage between product and process innovation, we confirm that because of learning and scale effects leaders have no incentive to invest in product innovation. Conversely, followers and/or newcomers have strong incentives to invest in product innovation dedicated to new potential markets but with less probability of success.

By distinguishing product and technology we show that products may encompass different complementary technologies that can have their own path and pace. Hence, product innovation does not necessarily affect the underlying technological knowledge and the related industry may display different dynamics than products.

Focusing on memory chips, logic chips and ASICs, we show that the intensity of knowledge obsolescence induces different effects on technological dynamics and subsequently on competition. Low knowledge obsolescence in memory chips gives rise to strong learning effect (Grupp, 2000) and promotes industry maturity where market leaders have a cost advantage. Logic chips experience a stronger knowledge obsolescence so that learning effect is lower mainly because full cost is not only dependent on production costs but also on design (and increasingly so). However, the emergence of a dominant design has provided the leader (Intel) with a competitive advantage induced by experience in design and strong network effects. We show that this leadership is closely related to the dominance of the computer market.

Unlike memory and logic chips, ASICs do not rely on a single technology but as a bundle of complementary technologies so that innovation does not rely on a single trajectory. Moreover, ASICs chips experience very strong knowledge obsolescence and are not dedicated to a specific market. While not new, this class of products relies on competing designs, from pure hardware solutions to embedded core-based concepts (software embedded in a chip) that include pre-designed, re-usable IP cores, data storage devices, DSP, bus control etc. While not standardised, the market for ASICs is not confidential (set top boxes, cellular phones, video games, intelligent dishwashers/fridges etc.). The reason for increasing differentiation is that knowledge or technology developed in a certain context may not be equally useful in other contexts. This is because there are context-dependent features in their production and in their use that cannot be readily translated when applied to different domains. Hence, the users may not find the technology useful when it is not developed by them, and tailored to their needs.

As a consequence, we show that the semiconductor industry as a whole is characterised by frequent periods of turbulence, product innovation and does not confirm any shakeout pattern of evolution. Far from contradicting life cycle patterns of evolution, we argue that a more general framework can allow us to take into account different levels of knowledge evolution and subsequent industry dynamics.

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