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AN EVOLUTIONARY AGENT-BASED SIMULATION MODEL FOR THE INDUSTRY LIFE CYCLE

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Abstract:

In contrast to the usual approach taken in the literature, in which an Industry Life Cycle (ILC) is reproduced by aggregate functions, the model of this paper generates a self-organizing ILC. A general evolutionary agent-based simulation model is developed that can be adapted for specific branches of industry. The results enable conclusions to be drawn for competition policy with regard to the workability of competition in the various phases of the ILC.

JEL-Classification: L10, L11, O12

Keywords: Industry Life Cycle, Agent-Based Simulation Model, Evolutionary Economics

I. INTRODUCTION

In the literature, the Industry Life Cycle (ILC) is mostly captured by models aiming to reproduce it in the form of an aggregate function or functions. By contrast, after a discussion about the type of suitable model, this paper develops a model that generates a self-organizing ILC in section III. However, no particular branch will be focused upon. Rather, it will be shown in Section IV, that just one model can generate an ILC for each branch specification, corresponding to the universal empirical validity of the ILC. Additionally, the results of such a model enable conclusions, in terms of competition policy, to be drawn with regard to the workability of competition in the phases of the ILC in alternative branches in Section V.

II. REFLECTIONS ON THE SIMULATION MODEL

To deal adequately with the universal empirical validity of the ILC, the model to be developed here should be able to depict a great number of branches. Hence it should be structurally adaptable to alternative technological regimes.

Essential characteristics distinguishing such regimes, or branches, are, first, the appropriability conditions in an industry, which determine firms' possibilities to generate an economic success based on technological and innovative achievements, and, second, the technological opportunities, which determine the ease of innovation for firms on the market. In the context of the knowledge base underlying the technological progress in an industry, technological regimes differ, first and foremost, in the cumulativity of knowledge which determines to what extent a firm's actual innovative successes also provide the basis for future innovative successes and, second, in the specificity of the knowledge base which determines the ease of imitation of an innovator by subsequent imitators.[1] Besides, the potential uncertainty on the market, or how well actors are informed, is critical for the type of competition in a branch.

In addition to the structural characteristics of technological change in an industry, or the structural characteristics of the knowledge base underlying the technological progress in this industry, it is also industrial economic characteristics that determine the type of competition in an industry. The extent of structural market entry barriers is particularly critical in this respect, whether these concern price or quality competition or the distribution of market power among the firms on the market.

In the modeling process described in section III, these structural characteristics of technological change in a branch and the relevant industrial economic characteristics are explicitly taken into account.

The first question to be dealt with concerns the type of model suitable for this purpose. As the present investigation focuses on industry evolutions, processes in industries will be examined in which competitive interactions occur between the economic subjects on the mar-

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[1] For discussion and definitions of distinguishing characteristics of technological regimes, see, e.g., Dosi (1984, pp. 86-89, and also 1988), Malerba and Orsenigo (1993).

ket in a self-organizing way. Contrary to the neoclassical approach, evolutionary economics focuses on the course of such processes, whereas the neoclassical approach neglects these as temporary processes of adapting to a long-term equilibrium, or considers them closed. In view of the problems outlined above, evolutionary economics is a more suitable theoretical paradigm and will therefore be considered in the modeling.

Furthermore, in contrast to analytical solutions simulations allow to determine results for given input parameters only. However, this supposed "inaccuracy" of the solutions of simulation models needs to be relativized because exact solutions are available in closed analytical models – exact only in a mathematical sense but not necessarily in an economic one.[2] As the subject addressed in this paper requires a model that can depict and compare alternative technological regimes in a flexible way, it is clear that this can be achieved by using alternative scenarios in the simulation analysis. In view of the fact that, by using alternative scenarios, alternative courses of evolution in the relevant industry system can be analyzed in a "comparative evolutionary" manner, a simulation model appears more suitable than a closed analytical one. Moreover, the industry evolutions under review are in principle based on competition processes and thus on the interdependent interactions of economic subjects. So the bottom-up perspective of agent-based modeling, which views a system from the perspective of the processes within it, seems more suitable than the alternative top-down perspective, which views the relevant industries to be modeled as whole systems.[3] In sum, it can be said that an evolutionary, agent-based simulation modeling fulfills all the requirements of the planned analysis, because it allows both for the self-organizing evolution of a system and the flexible consideration of alternative structural branch specifications.

III. THE MODEL

In the modeling, replicator dynamics is used as market mechanism in equation (1) for the simple reason that it is not focused on equilibria. It fulfills the requirements of evolutionary economics which, in section II above, was identified as an appropriate theoretical paradigm in terms of the subject of this investigation.[4] The competitiveness, $u_{i,t}$, as fitness is the central

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[2] Simulations allow an analysis with regard to the question "what would be conserved if 'the tape were played twice'" (Fontana and Buss 1994) by multiple (stochastic) simulation runs with the same initial parameters and thus conclusions within the bounds between chance and necessity. Thus, one can differentiate between systematic patterns and those of chance in the simulated evolutions. Hence simulation analysis creates "Erklaerungen des Prinzips" or rather "Mustervoraussagen" in the sense of Hayek (e.g., 1972).

[3] The agent-based modeling (ABM) allows the disaggregation of a model on the level of firm interaction. In this way, no explicit (macro) complexity needs to be modeled, but merely micro funded autonomous firms. The fundamentally evolutionary characteristics of economic subjects, i.e., bounded rationality and (behavioral) heterogeneity, can thus be implicitly accounted for by the ABM. By using ABM, the process characteristics of industry evolutions observed here come into being in a self-organized way, on the one hand, because of the structural conditions and, on the other hand, because of interactions of economic subjects. For ABM the object-oriented programming is suitable. For the present model the software „Laboratory for Simulation Development" (LSD) is used, developed by Valente (1998) and a freeware.

[4] Replicator dynamics assumes a rival relationship merely between heterogeneous economic subjects: economic subjects with above average competitiveness, valued at an endogenous average on the market, are more successful than those with a below average one. For example, firms with an above average competition win more consumers from competitors with a below average competition, and vice versa. For a detailed overview of the repli-

variable of replicator dynamics and serves as economic criterion for the evaluation of the differences between the relevant economic subjects, or "firms." To master the complexity of the model, the influences considered here on firms' competitiveness are restricted to the most important product characteristics from an industrial economic point of view: the price of the product, $p_{i,t}$, which is composed of the unit costs, $c_{i,t}$, and the mark-up, $\chi_{i,t}$,, and the technological performance,[5] $tP_{i,t}$,, depicts the quality of the product. In addition, the model considers a network-specific component, $u_t^{\xi\tau}$, depicting the competitiveness of a product in relation to the spreading of the product, or to the technology underlying it.

Firms can individually improve unit costs $c_{i.t}$ as well as the technological performance $tP_{i,t}$ of their products by research and development (R&D). Accordingly, the model differentiates between the imitative and innovative activities of firms. The budget for R&D $\vartheta_{i,t}$, depends on capital stock $K_{i,t}$ and on the R&D λ^{ϑ} share of the firm in (2) and, in (4), is shared out, on the basis of individual firms, between innovative $(.)^{inno}$ in (5) and imitative R&D$(.)^{imi}$ in (6). Therefore, R&D behavior is a source of behavioral heterogeneity of firms on market.[6]

$$(1) \qquad N_{i,t} = \left(\alpha \cdot \left(\frac{u_{i,t-1} - \overline{u}_t}{\overline{u}_t} \right) + 1 \right) \cdot N_{i,t-1} \cdot \gamma_t \qquad (2) \qquad \vartheta_{i,t} = K_{i,t} \cdot \lambda^{\vartheta}$$

$$(3) \qquad K_{i,t} = K_{i,t-1} + \left(p_{i,t} \cdot N_{i,t} - c_{i,t-1} \cdot K_{i,t-1} \right) - \vartheta_{i,t} \qquad (4) \qquad \lambda_{i,t}^{(\cdot)inno} = 1 - \lambda_{i,t}^{(\cdot)imi}$$

$$(5) \qquad \vartheta_{i,t}^{(\cdot)inno} = \vartheta_{i,t}^{(\cdot)} \cdot \lambda_{i,t}^{(\cdot)} \qquad (6) \qquad \vartheta_{i,t}^{(\cdot)imi} = \vartheta_{i,t}^{(\cdot)} \cdot \left(1 - \lambda_{i,t}^{(\cdot)} \right)$$

Important for a structural specification of technological regimes with regard to the characteristics of the knowledge base underlying technological progress are the cumulativity of knowledge, on the one hand, and the specificity of the knowledge base, on the other. The latter determines the ratio between the possibilities for imitation and for innovation. To depict this, the model uses the concept of spillovers because on a market without spillovers no imitation of an innovator is possible. Cohen and Levinthal (1990) stress that in order to interpret externally available knowledge, a firm needs to have the ability to do this, the so-called absorptive capacity. In the context of this capacity, Cantner and Pyka (1998) also discuss the influence of a firm's relative technological position in relation to the technological frontier as well as to last follower. Both are integrated into our model. Spillovers reflect the variety of knowledge that manifests itself in the variety of products on the market, or their characteristics. Thus (15) determines intra-industrial spillovers.[7] Besides, the model assumes that each

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cator dynamics principle, as introduced by Fisher (1930), a biologist, and its evolutionary foundations see, e.g., Metcalfe (1998).

[5] This product characteristic states to what extent the relevant product can satisfy a need. The assumption here is that a higher level of technological performance better satisfies a need. At the same time, this allows to limit the relevant market, whose industry evolution is being considered here, to the rival products with regard to this need.

[6] Heterogeneity of the economic subjects is one of the essentials of evolutionary economics. See, e.g., Silverberg (1997, p. 418).

[7] For an analogous determination of inter-industrial spillovers, see further below.

firm intentionally adapts its R&D allocation by redistributing it between imitative and innovative R&D with the help of routines. These allow, in (7), the correction of firms' budgeting in accordance with their current individual performance.[8] In this way, the model takes into account the requirements of learning economic subjects and of an evolutionary agent-based modeling in which agents follow simple routines and act autonomously.

To summarize, innovative versus imitative R&D activities are modeled as follows: On the one hand, based on an innovative R&D budget a knowledge stock is built up directly in (8), less an obsolescence rate $o^{(\cdot)inno}$. $\zeta^{\vartheta(\cdot)}$ is for weighting, whereas ι with (10) and (11) reflects the technological position of a firm relative to the technological leader and the last follower. On the other hand, based on an imitative R&D budget the absorptive capacity is built up in (12) and (13). So an imitative knowledge stock in (9) is indirectly built up, with the help of absorptive capacity $ac_{i,t}$, and depending on the technological position of firm ι, by assimilation of the available spillovers on the market $s_{t,}$.[9] Factors ζ^{ac} and ζ^{ι} are for scaling. Consequently, a total knowledge stock results from the innovative and the imitative parts in (17), with which a firm improves its technological performance as well as the unit costs of its product.

$$(7) \qquad \lambda^{(\cdot)}_{i,tj} = \begin{cases} \lambda^{(\cdot)}_{i,tj-1} & \text{for} \quad \iota^{(\cdot)}_{i,t-1} = 1 \\ \lambda^{(\cdot)}_{i,tj-1} + \lambda^{(\cdot)\beta}_{i,tj} + \beta^{(\cdot)ly}_{i,tj} + \beta^{(\cdot)bly}_{i,tj} & \text{else} \end{cases} \quad \text{with } \lambda^{(\cdot)}_{i,t} = [0{,}02;0{,}98]$$

$$(8) \qquad \Theta^{(\cdot)inno}_{i,t} = \Theta^{(\cdot)inno}_{i,t-1} \cdot \left(1 - o^{(\cdot)inno}\right) + \frac{\vartheta^{(\cdot)inno}_{i,t}}{\zeta^{\vartheta(\cdot)}} \cdot \iota^{(\cdot)}_{i,t}$$

$$(9) \qquad \Theta^{(\cdot)imi}_{i,t} = \Theta^{(\cdot)imi}_{i,t-1} \cdot \left(1 - o^{(\cdot)imi}\right) + s^{(\cdot)}_{t-1} \cdot I^{(\cdot)}_{i,t-1}$$

$$(10) \qquad \iota^{tP}_{i,t} = \frac{tP_{i,t} - tP^{Min}_{t}}{tP^{Max}_{t} - tP^{Min}_{t}} \qquad\qquad (11) \qquad \iota^{c}_{i,t} = 1 - \left(\frac{c_{i,t} - c^{Min}_{t}}{c^{Max}_{t} - c^{Min}_{t}} \right)$$

$$(12) \qquad ac^{(\cdot)}_{i,t} = 1 - \exp\left(-\zeta^{(\cdot)ac} \cdot \Theta^{(\cdot)ac}_{i,t}\right) \qquad\qquad (13) \qquad \Theta^{(\cdot)ac}_{i,t} = \Theta^{(\cdot)ac}_{i,t-1} + \vartheta^{(\cdot)imi}_{i,t}$$

$$(14) \qquad s^{(\cdot)}_{t} = \zeta^{(\cdot)} \cdot \left(s^{(\cdot)ia}_{t} + s^{(\cdot)ii}_{t}\right) \qquad\qquad (15) \qquad s^{(\cdot)ia}_{t} = \sqrt{\sum_{i=1}^{n} \left((\cdot)_{i,t-1} - \overline{(\cdot)}_{t}\right)^{2}}$$

$$(16) \qquad I^{(\cdot)}_{i,t} = \zeta^{ac} \cdot ac^{(\cdot)}_{i,t} \cdot \exp\left(-\frac{1 - \iota^{(\cdot)}_{i,t}}{\zeta^{\iota}} \right) \cdot \left(1 - \iota^{(\cdot)}_{i,t}\right) \qquad\qquad (17) \qquad \Theta^{(\cdot)}_{i,t} = \Theta^{(\cdot)imi}_{i,t} + \Theta^{(\cdot)inno}_{i,t}$$

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[8] Routines can be formulated in terms of a rule of thumb as if-else-conditions. The if-condition refers to the development of a relative firm position within an earlier period of time, and the resulting else-consequence refers to the appropriate redistribution of the R&D budget. To formalize this, see Appendix A.

[9] The possibilities of a firm to assimilate spillovers, marked with $I_{i,t}$, are implied by the combined influence of the relative technological position of a firm and its absorptive capacity. All possible $I_{i,t}$ result in a spillover function $F(I_{i,t})$ which follows the empirical example by Verspagen (1993) and Cantner (1995). The relative position ι^{*} that enables a firm to reach the maximum of the spillover function does not vary with an increase in absorptive capacity and depends on the technological distance to the technological frontier ($\iota_{i,t}$=1) and the last follower ($\iota_{i,t}$=0).

The buildup of knowledge stocks takes account of the cumulativity of knowledge in the modeling. Knowledge stocks are a further source of firm heterogeneity. Moreover, the modeling of R&D processes in firms depicts the specificity of knowledge bases by considering spillovers. For this reason, the possibilities of imitation can be varied gradually for the following scenario analysis in alternative regime specifications.

In addition, the modeling of firms' individual processes to improve technological performance based on a specific knowledge stock takes account of any uncertainty inherent in innovation processes due to stochastic distortions. The potential of individual firms to improve technological performance $tP_{i,t}$, in (18), grows with the extent of knowledge stock $\Theta_{i,t-1}$, built up imitatively and innovatively, but declines with the level already reached of technological performance $tP_{i,t-1}$. In this way, decreasing marginal revenues with constant R&D investments as well as the decrease of technological opportunities over time, as stressed, for example, by Dosi (1982), are endogenized in the model.

A multiplicative link to the probability of a successful innovation $\rho_{i,t}$, in (18), formalizes the uncertainty of the R&D process. An innovation in the sense of improving technological performance is modeled, following Cantner and Pyka (1998), by a comparison of a potential probability for a successful innovation with a random number ρ^{match}, in (19) and (20). The determination of the potential innovation probability ρ^{pot} also takes account of decreasing marginal revenue from technological opportunities over time. The variable ρ^{ζ} functions as weighting factor. The level of technological performance as the primary product characteristic of a firm is a further source of heterogeneity between the firms on the modeled market.

$$(18) \qquad tP_{i,t} = tP_{i,t-1} + \rho_{i,t} \cdot \left(\frac{\Theta^{tP}_{i,1-t}}{tP_{i,t-1}} \right), \text{ for } \forall i=1,\ldots,n$$

$$(19) \qquad \rho^{pot}_{i,t} = \exp\left(- \frac{tP_{i,t-1} + \dfrac{tP_{i,t-1}}{\Theta^{tP}_{i,t}}}{\rho^{\zeta}_{i,t}} \right) \qquad (20) \qquad \rho_{i,t} = \begin{cases} 0 & \text{if } \rho^{pot}_{i,t} < \rho^{match}_{i,t} \\ 1 & \text{else} \end{cases}$$

The second product characteristic is price $p_{i,t}$ of a firm's product, with the competitiveness of the product increasing as its price decreases. Because the price is composed of a mark-up $\chi_{i,t}$ and unit costs $c_{i,t}$ in (21), it can be lowered both by a firm's endogenous adaptation of the mark-up and a decrease of unit costs, based on experience effects. For modeling the effects resulting from experience, the empirical, branch-independently valid concept of the experience curve is used. On the basis of individual experience curves, in (24), and in accordance with their R&D investments, firms can improve their unit costs. The experience curve reflects the empirically substantiated, combined implications of multiple process innovations for the dynamic decrease of unit production costs. In this way, due to complexity, multiple sources of process innovations do not need to be considered in detail.

The potential to lower unit costs depends on the knowledge stock, which is built up imitatively and innovatively; it is thus analogous to technological performance. Accordingly, in (24), the experience coefficient of the firm, as part of the empirical concept of the experience curve, depends positively on the knowledge stock and negatively on an already achieved decrease of the firm's unit costs. Thus, decreasing marginal revenues from unit costs, which implicitly are an essential factor in the empirical concept of the experience curve, are integrated into the model. So experience coefficient $f_{i,t}$, in (22), depends on a firm's individual learning rate $l_{i,t}$, in (23), which, in turn, depends on a firm's individually built knowledge stock serving to improve unit costs.

$$(21) \qquad p_{i,t} = c_{i,t-1} + \chi_{i,t} \qquad\qquad (22) \qquad f_{i,t} = \frac{\ln(1 - l_{i,t})}{\ln 2}$$

$$(23) \qquad l_{i,t} = 1 - \exp(-\zeta^{l} \cdot \Theta^{c}_{i,t}) \qquad\qquad (24) \qquad c_{i,t} = \left(\zeta^{f} \cdot \frac{C_{i,t}}{C_{i,t-1}} \right)^{f_t} \cdot c_{i,t-1}$$

Not only are the effects of the experience curve on the decrease of unit costs a further source of firm heterogeneity in the model, but behavioral heterogeneity may equally result from firms' individual product prices. The decision on a mark-up $\chi_{i,t}$ by a firm determines whether a decrease of unit costs is passed on in the form of a decrease in prices to consumers. Firms' profits result multiplicatively from the number of consumers and the mark-up. Generally, the "law of demand" is assumed to apply to normal goods, meaning that a higher price decreases with the number of consumers of a product, leading to some strategic considerations regarding the interaction of price, number of consumers, and realized profit of a firm, relevant for determining a mark-up: On the one hand, the higher the mark-up the higher the profit of a firm, if the number of consumers remains constant; subsequently, both the capital stock and the R&D budget increase. In the same way, the experience coefficient of the firm increases, ceteris paribus, and the unit costs decrease, giving the firm an opportunity to subsequently increase its mark-up, without increasing the price, which, in turn, ceteris paribus, increases profit. On the other hand, the lower the mark-up, the lower the price, and the higher the increase in the number of consumers, ceteris paribus; if this increase is high enough, the loss per unit through a lower mark-up per unit is, in sum, compensated by a higher demand for the product. For this reason, a firm can increase its mark-up by precisely the amount saved through a decrease of unit costs, at the same time enabling it to maintain prices. For the same reason the potential for decreasing unit costs, created by experience effects, is important from a strategic point of view. To integrate this strategic aspect into the model, the mark-up is modeled, in (26), as a firm-individual proportional factor of the potential created by experience effects.

Based on the concept of routines, the firm can adapt its price to its individual competition situation as it develops, i.e., by a trial-and-error process (see Appendix A). In the model, every firm increases its mark-up whenever the number of consumers has increased or remained constant in the relevant part of past, and vice versa. This modeling, in (27), allows firms to determine their product prices without any knowledge of the aggregate market demand or any exogenous demand curve, but merely on the basis of a routine that is intuitively reasonable.

$$(25) \qquad \Pi^{netto}_{i,t} = \chi_{i,t} \cdot N_{i,t} \qquad\qquad (26) \qquad \chi_{i,t} = \chi_{i,t=0} - \left(\psi_{i,t}\left(c_{i,t=0} - c_{i,t-1}\right)\right)$$

$$(27) \qquad \psi_{i,tj} = \psi_{i,tj} + \psi^{ly}_{i,tj} + \psi^{bly}_{i,tj}$$

This adaptive learning process, which considers the interactive dependence of an individual firm on its unique competition ecology in terms of the firm's own demand development, takes into account the requirements of an evolutionary and agent-based modeling with regard to micro foundation, besides creating heterogeneity of firm behavior on the market.

In addition, the firm has to share out its R&D investment between one budget for the improvement of technological performance and one for the improvement of unit costs. For this budgeting, too, in (30), the model provides a routine, serving firms to assesses which R&D investments have improved firms' position more and which less, in the relevant period (see Appendix A). In this way, the firm, analogously to the redistribution of the R&D budget between imitative and innovative R&D, adapts its R&D investment by way of an individual trial-and-error process.

$$(28) \qquad \vartheta^{tP}_{i,t} = \vartheta_{i,t} \cdot \lambda_{i,t} \qquad (29) \qquad \vartheta^{c}_{i,t} = \vartheta_{i,t} \cdot \left(1 - \lambda_{i,t}\right) \qquad (30) \qquad \iota_{i,t} = \frac{\left(\iota^{tP}_{i,t} + \iota^{c}_{i,t}\right)}{2}$$

$$(31) \qquad \lambda_{i,tj} = \begin{cases} \lambda_{i,tj-1} & \text{for} \quad \iota^{c}_{i,t-1} = 1 \quad \text{or} \quad \iota^{tP}_{i,t-1} = 1 \\ \lambda_{i,tj-1} + \lambda^{\beta}_{i,tj} + \beta^{ly}_{i,tj} + \beta^{bly}_{i,tj} + \beta^{\iota}_{i,tj} & \text{else} \end{cases}$$

with $\lambda_{i,tj}$ =[0,02; 0,98]

After the supply side of the market has been completely described in detail, the demand side will be focused upon. To this end, the model assumes an aspiration level for each consumer following Simon (e.g., 1956). The aspiration level expresses the bounded rationality of consumers, which can be used to meet the requirements of evolutionary modeling. By the maximal benefit that the products earn on the market, in (32), the potential of consumers can be distinguished into a developed market potential, representing the group of consumers whose aspiration level is not higher than the maximal product benefit on the market, and a non-developed market potential. The perception of this maximal product benefit on the market by consumers, in (34), is distorted, but the intensity of the distortion decreases over time through learning by using, for example. The modeling thus takes account of the characteristics of the development of preferences within technological paradigms with regard to decreasing uncertainties, as stressed, for example, by Dosi (1982). Besides, the model assumes that individual consumers cannot immediately recognize the best product. It is only the replicator dynamics that causes a redistribution of consumers from inferior to superior products. In the model, both distortions in the consumers' perceptions reflect their limited knowledge and bounded rationality, which meets the requirements of evolutionary modeling. As the endogenous increase of the maximal product benefit determines the extent of the increase in market potential, in (33), market growth can be endogenized.

In (35), an evolution of the demand side is integrated into the model on the additional assumption that consumers' individual aspiration levels increase due to the use of products on the market if maximal product benefit on the market increasingly exceeds the aspiration levels of all consumers, in (36), by φ_t. Consequently, this increase in consumers' individual aspiration levels in relation to the current market development in the model is a simplified interpretation of von Weizsäcker's (1971) concept of endogenous preferences. In particular, von Weizsäcker (2004, pp. 17) stresses the anti-evolutionary character of the neoclassical assumption of fixed preferences. Hence the integration of an endogenous evolution of the demand side, as an endogenously modeled adaptation of individual aspiration levels, accounts for the requirements of an evolutionary modeling, allowing, moreover, to depict a diminishing market potential in the subsequent scenario analysis.

$$(32) \qquad N^{pot} = N_t^{dev} + N_t^{ndev} \qquad\qquad (33) \qquad \gamma_t = \frac{N_t^{dev}}{N_t^{ndev}}$$

$$(34) \qquad N_t^{dev} = \left(1 - \frac{\Phi_t^{Max} - \varepsilon\left(u_t^{Max}, t\right)}{N^{pot}}\right) \cdot N^{pot}$$

$$(35) \qquad \Phi_t^{Max} = \begin{cases} \Phi_{t-1}^{Max} \cdot \varphi_t & \text{if} \quad \varphi_t > \overline{\varphi}_t \\ \Phi_{t-1}^{Max} \cdot \overline{\varphi}_t & \text{else} \quad \text{with} \quad N_t^{dev} > N^{min} \end{cases} \qquad\qquad (36) \qquad \varphi_t = u_t^{Max} / \Phi_t^{Max}$$

The last component that influences the competitiveness of products on the market in the model is network specific. The greater spreading of a product increases its competitiveness, as well as that of compatible products due to the network benefit, in turn increasing consumers' interest in the product or compatible products. To evaluate the spreading of a product technology, in (37), both the installed base and the expected base, in (38), are important. The latter is determined by the development of an installed network base and of a spreading of compatible product technologies, depending on the compatibility factor of product technologies κ. This feedback effect derived by a user network is called network effect, in (40).

$$(37) \qquad \Xi_t^{\tau install} = \sum_{i=1}^{n_\tau} N_t^\tau \qquad\qquad (38) \qquad \Xi_t^{\tau \exp} = \Xi_t^{\tau einstall} \cdot \zeta^{\xi\tau} \cdot \left(\frac{1}{4} \cdot \frac{\Xi_t^{\tau install}}{\Xi_{t-3}^{\tau install}}\right)$$

$$(39) \qquad \Xi_t^\tau = \left(\Xi_{t_x}^{\tau install} + \Xi_{t_x}^{\tau \exp}\right) + \kappa^{\tau x \to \tau y} \cdot \left(\Xi_{t_y}^{\tau install} + \Xi_{t_y}^{\tau \exp}\right) \qquad (40) \qquad \xi_t^\tau = \tanh\left(\nu\left(\omega + \Xi_t^\tau\right)\right)$$

To summarize, the fitness of a product on the market, which determines the benefit of the product for consumers, can be described in a three-dimensional characteristic space,[10] in (44): a specific product price, a specific technological performance, and the network-specific benefit component of the product.

$$(41)\qquad u^{tP}_{i,t} = \eta^{tP} \cdot tP_{i,t} \qquad\qquad (42)\qquad u^{P}_{i,t} = \eta^{P} \cdot \left(1 - e^{-\left(\frac{\zeta^{up}}{p_{i,t}}\right)}\right)$$

$$(43)\qquad u^{\xi\tau}_{t} = \eta^{\xi} \cdot \xi^{\tau}_{t} \qquad\qquad (44)\qquad u_{i,t} = u^{tP}_{i,t} + u^{P}_{i,t} + u^{\xi\tau}_{t}$$

In (41)-(43), the importance of such components of product benefit η can be regime-specifically varied for the purpose of analysis.[11] To depict processes of competition and simultaneously account for the requirements of evolutionary modeling, the model must be able to account for market entries and exits. In this way, influences of the industrial evolution are included in the model that extend beyond the system boundaries of the hitherto closed, modeled industry or branch. A further influence that crosses system boundaries derives from inter-industrial spillovers which, in the model, next to intra-industrial spillovers, are a source of knowledge generated outside of the firm, which can be used by firms on the market to accumulate imitative knowledge.

For this, the idea of Winter (1984) with regard to an industry-external (imitative and innovative) R&D activity is taken up which is relevant for the industry itself inasmuch as alternative products to those in the industry are manufactured. The formal modeling of the development of the corresponding product characteristics ($(.)^{back}$), generated on the basis of the knowledge stock, in (45), by background R&D activity, is analogous with (18)-(20) and (22)-(24).

$$(45)\qquad \Theta^{(\cdot)back}_{i} = \Theta^{(\cdot)back}_{t-1} \cdot \left(1 - o^{(\cdot)back}\right) + \frac{\vartheta^{(\cdot)back}_{t}}{\zeta^{\vartheta(\cdot)}} \cdot \iota^{(\cdot)back}_{t}$$

Based on the ratio between industry-external and industry-internal levels of knowledge, the inter-industrial knowledge variety can be formalized analogously to the intra-industrial spillovers stemming from the industry-internal knowledge variety. Moreover, the assumption of industry-external product alternatives allows the modeling of innovative market entry. In addition to innovative market entry, imitative market entry is also modeled, the latter depending on the profit possibilities on the market. Because the model is micro funded to take into account an evolutionary agent-based modeling, the assumption is that an above normally firm potentially provokes entry of a new competitor. Should market entry occur,

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[10] The concept of a multidimensional characteristic space for describing products and its variants is formulated by Lancaster (1966).

[11] Moreover, regime specifically, this creates the possibility of the parallel existence of a price and a quality leader (with regard to technological performance) and thus of a firm's product differentiation in the sense of niche creation.

the provoking firm provides the new (provoked) entrant with an imitation pattern with regard to price and technological performance of the product.[12]

The assumption of a uniformly distributed phase of market observation in the interval $[0,B^{max}]$, in which potential entrants decide on their entry, and the stochastic distortions of the initial equipments of new entrants, reflect the uncertainty of market entry processes and are also an important source of firm heterogeneity in the model. By including market growth in the modeling of the market entry process, the model accounts for the expectations of potentially new firms as to whether it would be worth their while to enter the market.

Finally, firms' market exit is formally integrated into the model by assuming a critical lower limit of capital stock, which a firm may fall short of only for a certain, critical number of periods before exiting, the point being that otherwise a firm would not have enough financial resources to invest in R&D and thus to improve its products.

IV. SIMULATION RESULTS

IV.1 SCENARIO CONFIGURATION

Both the initial conditions of each scenario configuration as well as stochastic events influence the actual development of the modeled system in a single simulation run which describes a specific evolutionary process of an industry. As the results of a simulation run are path dependent due to stochastic influences, multiple simulation runs, using an identical scenario configuration, are necessary to generate contingent evolutions of this scenario configuration. In this way, the typical systematic characteristics of the "biography of the scenario evolution" can be distinguished from stochastic, not systematically occurring characteristics. For the simulation model developed here, 1,000 simulations were run for each scenario configuration. The scenario-specific simulation results are average values (and deviations) of these individual 1,000 simulations runs per scenario.

In addition, the reactions of the simulation model to parameter variations need to be considered. These specific parameter configurations enable a systematic experimentation with the model. The reactions of the modeled system to controlled parameter variations can thus be analyzed with regard to the implications and importance of single parameters, or system components, in relation to the other parameters and system components.

As the simulation model developed here serves to depict technological regimes, six (groups of) model parameters will be varied for the scenario configuration, depicting structurally alternative technological regimes or alternative industrial economic conditions in the simulated industries.[13] To meet the critique of Windrum (2007) that the output of simulation models in the simulation-analytical literature is usually merely illustrative and not verified by a sufficient number of simulation runs, we vary each (group of) parameters threefold for sce-

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[12] For reasons of clarity, see Lehmann-Waffenschmidt (2006) for a full depiction of market entry processes.

[13] For this, see Appendix A. In addition, see Appendix A for the scenario-independent parameters, stochastic variables, and initialized firm-specific variables.

nario configuration to perform a systematic analysis of the simulation model.[14] The first group of parameters influences the market growth endogenously reachable within the simulated market.[15] In the first case, the market potential (MP) is not fully developed until the end of the simulated period so that the relevant market continues to grow during the period under review. (MP↑) In the second case, the developed market potential continues to grow during the simulated period until reaching the potential's limit and then remains constant. (MP→) In the third case, the developed market potential keeps growing until the potential's limit is reached, whereupon the individual aspiration levels of consumers co-evolve along with the (maximal) product benefit produced on the market, as shown in section III, and the relevant market starts to shrink. (MP↓) Furthermore, to depict the structurally determined possibilities of the ease of entry of new firms, the level of market entry barriers is varied (minMEB, mMEB und maxMEB)[16] as well as the structural level of knowledge spillovers to depict the possibilities for imitation available on the market (minSpo, mSpo und maxSpo). Besides, the replicator speed is varied to depict the speed of environmental change confronting firms[17] (minα, mα und maxα). Likewise, the number of firms forming the basis of a scenario is also varied to depict the prevailing balance of power on the market at the beginning of the development of a modeled industry, in the sense of a historically evolved, initial situation for a relevant competitive development in the simulated period of time (2U in t0, 6U in t0, 10U in t0). Finally, the influence of technological performance tP and price p on product fitness, as seen by consumers, is varied to depict the type of competition in an industry, in the sense of quality competition versus price competition (tPregime, pregime, tPpregime).

By the threefold variation of the six parameter (groups) and the performance of 1,000 simulation runs per scenario, the output of the simulation model developed here can be verified systematically, rather than only illustratively, in accordance with the requirement of Windrum (2007). The result is $3^6=729$ scenarios (with 1,000 runs each), that is, a total of 729,000 simulation runs.

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[14] This produces 729 scenarios. To distinguish stochastic distortions from systematic developments, 1,000 runs per scenario were simulated so that simulation results per scenario occur as average values of each with one exception. Average values are not appropriate for market structure developments of firms on the market, because a specific market structure and its development can only be adequately assessed by depicting the firm's individual market shares. That is why, for an analysis of market structure developments, the results of those single simulation runs are selected that are characteristic of a specific scenario.

[15] This first parameter group also influences the possibilities to build up knowledge stocks of firms on the market. Simulation results that are implicitly based on an endogenous development of levels of knowledge stocks are comparable only within types of alternative market growth scenario.

[16] The weighting of market growth in case of an innovative market entry process and the weighting of profitability of an established firm in case of an imitative market entry process as well as the maximal period for market observation of a new firm are especially important in this respect.

[17] However, it is not the absolute replicator speed that is decisive for market structure development, but the ratio of firm's individual possibilities for an adaptation to the speed of changing environmental conditions. This ratio reflects how strongly a firm can gain from a fitness advantage or rather is punished due to fitness disadvantage. Therefore, this ratio of market changes to speed of firm adaptations reflects, implicitly at least, this part of the appropriability conditions on the market that is structurally caused.

IV.2 THE ILC IN THE SIMULATION RESULTS

As a first step in the analysis of the simulation results, the development of the number of firms, entries, and exits in the various scenarios can be compared graphically with the general development of the ILC summarized in Diagram 1 in a stylized way. Diagram 2 shows the examples of nine simulated scenarios. The conformity with this pattern of evolution is evident in the direct comparison with Diagram 1.

The evolution of variables in the simulated MP↑ scenarios is slower than in scenarios with MP→ or MP↓. The standardized ordinate in Diagram 2 clearly shows the higher level of the number of firms, entries, and exits in MP↑ scenarios compared to MP→ or MP↓ scenarios. But the ILC pattern of the interdependent development of the number of firms, entries, and exits according to the empirical stylized fact of industry evolution in the form of the ILC is evident in all scenario configurations in Diagram 2.

Klepper und Graddy (1990) distinguish three ILC phases: The takeoff of the number of firms is followed by a shakeout of firms with decreasing intensity over time until, finally, the remaining number of firms becomes stabilized. To define the beginning of the third phase, Klepper and Graddy (1990) assume that the number of firms falls below 75% of the maximally reached number and its periodical change does not exceed 1% of this maximum. However, of the 46 evolutions of industry developments examined by Klepper and Graddy (1990) only 22 reach the third phase, while 8 did not even experience a shakeout. [18]

This alternative pattern of evolution, where industries pass only partly through the ILC phases, is also reflected in some simulation results. All maxα scenarios clearly reach the final phase of a stabilization of the number of firms, though Diagram 2 already shows that mα-tPpregimes reach a relative stabilization of the number of firms only very late in the simulated period. In mα-MP↑-minMEB scenarios, only pregimes reach the last phase of stabilization of the number of firms, but not tPp- and tPregimes.

This alternative pattern of evolution is even more pronounced in the majority of minα scenarios in which the phase of stabilization of the number of firms after a shakeout is not reached. In scenarios with low replicator speed (minα), firms are able, because of the low speed of environmental change in relation to the individual possibilities of firms for adaptation, to counteract disadvantageous developments, for example by price adaptation. Hence behavioral adaptation dominates the selective forces, and firms can individually take measures against a potential exit so that, at the system level, a relatively "weak" shakeout of the number of firms is observed only at a very late stage, if at all, as shown in Diagram 3.

The pregimes in the group of MP↑-minα scenarios do not even reach their maxima in the evolution of the number of firms and thus not even the beginning of a shakeout. The same is true for tPregimes in this scenario group when market entry barriers are relatively high

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[18] Evolutionary patterns which differ from the typical stylized ILC are discussed, e.g., in Utterback (1994), Klepper (1997), Rycroft and Kash (1999), and Bonaccorsi and Giuri (2000).

(mMEB, maxMEB). As expected, the tPpregimes take an intermediate position between the tP- and the pregimes in this scenario group.

To observe the evolution of the simulated industries in detail, the phase concept of the ILC according to Klepper and Graddy (1990), with only two developmental and one residual phase, is expanded. First, we look at the phase concept of Agarwal and Gort (1996) whose concept is a refined version of Gort and Klepper's phase concept (1982). They distinguish five ILC phases, based on the development of net entries: in phase 1, only few firms are to be found. Phase 2 is characterized by high net entry. Agarwal and Gort differentiate two parts of this phase, the first part showing an increase in net entry, the second part a decrease. In phase 3, net entry is approximately zero because entries and exits are nearly equal, with the number firms remaining relatively constant. Phase 4 is characterized by negative net entry, where the authors again distinguish a first part showing an increasing and a second part showing a decreasing intensity of negative net entry. Finally, phase 5 shows no consistent trend of net entry. However, the short description of this concept illustrates that the division of the phase concept is not sufficiently exact to capture the transitions from phases 1 to 2, 3, and 4. Only the transitions from 2a to 2b and 4a to 4b can be divided exactly. For a detailed analysis of the 729 simulated scenarios this concept is thus unsuitable.

By contrast, the phase concept of Klepper and Graddy (1990) allows for an exact division of the phases, as discussed above, and serves as a basis for the refined phase concept presented here. For a better overview, Diagram 4 graphically summarizes the phase concepts of Agarwal and Gort (1996) (P-5 A/G), Klepper and Graddy (1990) (P1-3 K/G), and the refined phase concept (roman numbered: Phases I-V) to be applied here, in which the first and second phases of K/G are further subdivided. The phase of the increasing number of firms according to K/G can be subdivided into a Takeoff Phase I, comprising the number of entries and thus the number of firms until the number of entries reaches its maximum, followed by an Exuberance Phase II, reflecting an "effusive" further increase in the number of active firms until this number reaches its maximum, at which point the number of further entries is beginning to decrease. The second stage of evolution, according to K/G, is subdivided into a Shakeout Phase III, comprising the number of firms in which the number of entries decreases, while, at the same time, the number of exits continues to increase until reaching a maximum, and into a Slowdown Phase IV, in which the number of firms decreases further, but the number of exits slowly decreases so that the decrease of the number of firms slows down in this phase. This is followed by the Stabilizing Phase V, comprising the number of firms with stochastic entries and exits, analogously to the residual phase of K/G.

Table 1 shows that the evolution of the number of firms on the market can be understood on the basis of the simulation data reflecting the five stages of the ILC, as defined above. In this connection, special attention is given to the number of entries and exits, to the net entry used by Agarwal and Gort (1996) in their phase concept, and the rate of net entry showing the ratio of net entry to the total number of firms on the market.

The number of entries and net entry as well as the rate of net entry peaks in Takeoff Phase I of the ILC. The maximum of exits as well as the negative maximum of net entry are reached in Shakeout Phase III. Net entry therefore decreases from Takeoff Phase I to Exuberance Phase II of the ILC and, after its negative maximum in Shakeout Phase III, slowly approximates to zero in Slowdown Phase IV of the ILC. This trend increases in Stabilizing Phase V of the ILC. By contrast, the rate of net entry reaches its negative maximum only in Slowdown Phase IV, because up to this phase the number of firms has decreased to an extent where negative net entry has assumed greater importance and the rate of net entry may be lower than in Shakeout Phase III.

The developments of net entry, or the rates of net entry, observed in the simulation results, also correspond to empirical findings, for example, by Gort and Konakayama (1982) and Klepper (1996a): In the early phases of industry evolution, entry rates exceed exit rates and this relation is reversed in later stages of evolution. The empirical data of Agarwal and Gort (1996) are also consistent with the simulation results in Table 1.[19]

In sum, it can be said that the behavior of the modeled industry system, as observed in the simulation results, is consistent with the empiricism of the ILC.[20]

V. IMPLICATIONS FOR COMPETITION POLICY

From the point of view of competition policy, the workability of competition[21] can be analyzed from three perspectives in the model developed here: First, on the basis of a desirable *market structure*, for example in terms of product differentiation and market concentration, and, second, on the basis of a desirable market behavior, for example in terms of the level of prices on the market; and, third, on the basis of desirable market results, for example in terms of product quality or a high rate of technological progress.

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[19] The maximum rate of net entry in the phase concept of Agarwal und Gort (1996) is reached in the 1. A/G phase, and, because of the different phase definition (see Diagram 4), the maximum of the exit rate is reached in the 4. A/G phase. The net entry rate of Agarwal and Gort (1996) is not calculated explicitly and based on own calculations.

[20] In this context, besides the behavior of the modeled industry system as a whole, the behavior of the simulation model depending on each parameter (group) to generate scenarios can be discussed. For reasons of limited space, see Lehmann-Waffenschmidt (2006) for further details. In the following, only selected results are depicted. For a detailed discussion and depiction, see also Lehmann-Waffenschmidt (2006). For reasons of evaluation, i.e., for compatibility with empirical data that are based mostly on annual figures, simulation results will be partly adjusted referred to as "annual." Interpreting a simulation period as a quarter of a year, the adjusting of data is performed for four simulated periods, whereas mean values for phases are calculated on a periodical basis. Hence, in the following, the simulation data adjusted for four simulated periods are explicitly referred to as "annual."

[21] Originally, the idea of a "Wettbewerbsleitbild" of a "Funktionsfähiger Wettbewerb" or rather "Workable Competition" goes back to Mason (1939) and is developed further above all by Clark (1940, 1961), Eucken (1952), and Kantzenbach (1967). A "Wettbewerbsleitbild" is a bundle of economic policy objectives which can be consistently deduced from competition theory. For this short statement, see Blum und Veltins (2002, pp. 6) but also, e.g., Bartling (1980) and for an overview of the „Wettbewerbsleitbild" of „Funktionsfähiger Wettbewerb," e.g., Blum (2004), pp. 472-500. The main statement of the „Wettbewerbsleitbild" of „Funktionsfähiger Wettbewerb" is that technical progress is most strongly supported by a market structure with moderate concentration in a wide oligopoly and moderate product heterogeneity. In this type of market, the competition intensity is therefore optimum.

First, with regard to a desirable market structure, the simulation results[22] can be checked for scenarios showing a high product differentiation to assess the workability of competition. For this, the variety of technological performance on the market can be considered:

In simulated price regimes, product heterogeneity on the market is always greater than in tPregimes where the quality criterion is of great importance for an evaluation of the competitiveness of products on the market. In early phases of the ILC, there is a relatively high instability in the scenarios with price regimes, and the market structure is characterized by tendencies toward temporary monopolies and switching patterns. In addition, the degree of concentration on the market in the later phases of evolution is lower in scenarios with price regimes than in scenarios where the technological performance is considered rather important for consumers' evaluation of products on the market. The market structure of stable oligopolies in the last phases of the ILC is typical for scenarios with price regimes.

Second, the quality of competition can be evaluated in terms of a desirable *market behavior* with regard to the level of prices in relation to the level of mark-ups on the market.

If we assume that an increasing competition pressure is reflected in a decreasing level of mark-ups, this pressure would always be higher in scenarios with price regimes than in those where the technological performance, rather than the price, is of great importance for the fitness of firms. For the higher the structural importance of prices for the fitness of products in the simulated scenarios, the lower is the level of mark-ups on the market. Besides, the price tends to fall to a lower level, the lower the structural market entry barriers are. And last but not least, the price level is higher, for example, in a growing market than in a constant or shrinking market. But above all else, the simulation results clearly demonstrate that the price-performance ratio improves substantially in industry evolution, both in scenarios with price regimes and in scenarios in which technological performance is a dominant factor in consumers' evaluation of products on the market.

If, from the perspective of a desirable *market result*, one interprets the quality of competition as being higher when technological progress is promoted more strongly, simulation results show that the highest levels of quality are mostly reached in those scenarios in which technological performance, as a criterion of the technological product quality is considered as the most important structural element – structural as defined by consumers' interests – of product fitness. Monopoly tendencies are typical for the late evolutionary phases of such industries. These tendencies are caused by the innovative advantage of the biggest firm on the market due to the strong cumulativity of technological progress and are, for this reason, not disadvantageous to competition in terms of the rate of technological progress, but rather promote competition more than a "fragmented" market structure, which would, accordingly, result in an equally "fragmented" promotion of technological progress. Moreover, for the same reasons, the levels reached of technological performance increase in the scenarios

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[22] For a detailed overview of the simulation results analyzed here only verbally, see Lehmann-Waffenschmidt (2006).

along with increasing market entry barriers, because the smaller number of competitors on the market also has a positive effect, in terms of the cumulativity of technological progress, on opportunities for the improvement of the technological performance of products.

The discussion about higher levels of technological performance reached on the market in scenarios in which technological performance is of great importance for consumers' evaluation of products on the market clearly shows that higher mark-ups may well be desirable if the resultant, greater financial power of firms also results in greater R&D efforts.

The rate of technological progress with regard to technological performance reaches, relatively early, a significantly higher maximum in price regimes compared to tPregimes in which technological performance is of high, but the price of this performance of little, importance to the fitness of firms. This higher maximal rate of technological progress is caused by a considerably faster development of consumer potential, providing more income for firms and thus a potentially greater R&D budget for the improvement of technological performance.

To summarize, it can be said that even this brief discussion about the quality of competition from the perspectives of market structure, market behavior, and market results shows that the simulation results do not provide a clear identification of any single type of market which, more than other types of markets, promotes the technological progress in all scenarios and throughout the entire simulated industry evolution. The discussion also shows that the evaluation of competition processes according to the rate of technological progress alone is not suitable to localize an "optimum" competition intensity. In view of the simulation results, a static perspective must therefore be considered unsuitable for the evaluation of competition. Instead, for the evaluation of competition processes, the simulation results clearly demonstrate the importance of the phase-specific view of industry evolution, on the one hand, as already stressed by Heuss (1965) in his theory of market phases, as well as the importance of structural regime conditions underlying an industry evolution, on the other.[23]

With regard to the evaluation of competition in terms of the rate of technological progress, the simulation results phase specifically show the highest rates of technological progress as well as of improvement in the price-performance ratio during the early phases of the ILC (Phases I and II). In subsequent phases of development, however, the rate of technological progress tends to decrease. The results also show that, in the early phases of the ILC, the biggest share of technological progress is generated by young firms, which means that most of the know-how necessary for innovations also derives from innovative new entrants. It would follow that the creation of possibilities for the market entry of new firms is vital in terms of competition policy and should be promoted.

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[23] Competition policy is dependent on the underlying technological regimes in an industry and in this respect industry specific, as stressed also by Breschi et al. (2000).

However, for the later phases of the ILC the simulation results show that young firms hardly play an important role, neither in competition on the market nor in technological progress. Agarwal et al. (2002), for example, conclude from this that there is a need for a time-dependent or, with regard to the development of the ILC, a phase-dependent evaluation of the new entries of firms as well as of entry and survival rates. Analogously, from the perspective of competition policy, a time- and phase-dependent evaluation of competition processes with regard to market entry barriers and market entry opportunities is equally essential.[24]

In sum, the actual rate of technological progress and its evaluation essentially depend on the relevant structural regime specifications, on the one hand, and the localization of the relevant competition situation in its respective ILC, on the other. Obviously, in this sense the rate of technological progress can never be an "optimum" one.

For this reason, a dynamic perspective, too, is just as unsuitable for an evaluation of competition processes. From the point of view of competition policy, an evolutionary perspective is required for such an evaluation, which includes a historical perspective on the development of competition processes, that is to say, in the context of their particular ILC localization. Blum and Veltins (2004, pp. 187) thus conclude "that the evolutionary nature of economic processes should receive greater attention. In a period of technological drives, an important part of the economy is in constant transition. Developmental trends are considerably by irreversibilities, i.e., the possibilities deriving from a basic innovation are perceived and exploited until development enters a more stable, mature phase for which "classic antitrust law" has been made."[25]

Analogous conclusions are possible with regard to the above mentioned theoretical concept of the diffusion speed of innovative lead profits, according to Kantzenbach (1967), to measure competition intensity, if one compares this concept of competition intensity with that of technological regimes. A technological regime is defined by the fundamental characteristics of the technological change in a branch or the characteristics of a knowledge base underlying the technological progress in a branch. In this context, the essential characteristics of technological change in a branch, or the characteristics of knowledge bases, are, first, the appropriability conditions[26] which determine to what extent a firm on the market can translate a competitive advantage into a financial success and protect itself against imitation. Second, it is the technological opportunities that determine how substantial a firm's competitive advantage, due to product improvements, etc., can be relative to its competitors on the market, in this way reflecting the "ease" of innovation. Third, it is the specificity of a knowledge base that determines the "ease" of imitation, and, fourth and last, the cumulativity of knowledge that determines to what extent current advances in knowledge will influence future ones.

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[24] Eichner (2002), e.g., discusses the possibilities of an industry policy to strengthen competition depending on the current development phase of the relevant industry.

[25] Translated by the author.

[26] For a definition of appropriability conditions, see e.g., Malerba and Orsenigo (1993).

However, the essential variable of the Kantzenbach concept of competition intensity is the speed that determines how fast imitators on the market are able to "eat up" lead profits of an innovative firm.[27] Accordingly, the definition of the entrepreneurial possibilities to build up innovative leads, as outlined in the concept of technological regimes,[28] is directly complementary to Kantzenbach's concept of competition intensity, as shown by the brief discussion of this aspect above.

If one takes into account that, first, the characteristics of regime-specific knowledge bases can only in part be structurally determined and, second, largely develop endogenously within the historical industry evolution, it becomes clear that this is also true for competition intensity on the market. Consequently, the Kantzenbach concept of competition intensity cannot be interpreted as a static, structural concept, which explains the difficulty to identify an optimum type of market in terms of guaranteeing an optimum competition intensity for the promotion of technological progress. Rather, competition intensity itself evolves endogenously in the course of the historical evolution of an industry, and this specifically historical endogeneity needs to be taken into account in the evaluation of competition processes with the aspect of competition policy in mind.

VI. SUMMARY

The model developed here allows to simulate self-organizing, endogenously evolved industry developments in alternative branch specifications, which develop in accordance with the empiricism of the ILC. The model is therefore suitable for analyzing industry evolutions in detail. For reasons of space, see Lehmann-Waffenschmidt (2006). In the context of this model, it was further possible to discuss, in greater detail, aspects of competition policy with regard to the workability of competition, or of an optimum competition intensity, in the different phases of the ILC and in different scenario specifications.

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[27] See, e.g., Bartling (1980), pp. 30 ff., for a critique of the Kantzenbach concept of competition intensity, which only focuses on the "nachstoßenden" part of Schumpeterian competition, namely the speed with which imitators catch up on an innovative lead. However, the Kantzenbach concept does not observe the "vorstoßenden" part of the Schumpeterian competition, namely the innovative initiative of the innovators. For a detailed discussion of the "vor- und nachstoßenden" competition, see Eichner (2002).

[28] The concept of technological regimes is understood as a combination of the essential characteristics of technological change in a branch, or the characteristics of a knowledge base, which underlies the technological progress in a branch.

VII. APPENDIX

VII.1 APPENDIX A

FIRM-SPECIFIC VARIABLES FOR ROUTINES

	if: $\iota^{(\cdot)}_{i,tj-2} < \pi \cdot \iota^{(\cdot)}_{i,tj-3}$			if: $\iota^{(\cdot)}_{i,tj-2} \geq \pi \cdot \iota^{(\cdot)}_{i,tj-3}$		
if: $\lambda^{(\cdot)}_{i,tj-2}$ zu $\lambda^{(\cdot)}_{i,tj-3}$	>	=	<	>	=	<
then: $\beta^{(\cdot)bly}_{i,tj} =$	$-\beta^{\lambda bly} \cdot \lambda^{\beta}$	0	$+\beta^{\lambda bly} \cdot \lambda^{\beta}$	$+\beta^{\lambda bly} \cdot \lambda^{\beta}$	0	$-\beta^{\lambda bly} \cdot \lambda^{\beta}$

	if: $\iota^{(\cdot)}_{i,tj-1} < \pi \cdot \iota^{(\cdot)}_{i,tj-2}$				if: $\iota^{(\cdot)}_{i,tj-1} \geq \pi \cdot \iota^{(\cdot)}_{i,tj-2}$			
if: $\lambda^{(\cdot)}_{i,tj-2}$ zu $\lambda^{(\cdot)}_{i,tj-3}$ if: $\lambda^{(\cdot)}_{i,tj-1}$ zu $\lambda^{(\cdot)}_{i,tj-2}$	>	=	= & =	<	>	=	= & =	<
then: $\beta^{(\cdot)ly}_{i,tj} =$	$-\beta^{\lambda ly} \cdot \lambda^{\beta}$	0	0	$+\beta^{\lambda ly} \cdot \lambda^{\beta}$	$+\beta^{\lambda ly} \cdot \lambda^{\beta}$	0	0	$-\beta^{\lambda ly} \cdot \lambda^{\beta}$
then: $\lambda^{(\cdot)\beta}_{i,tj} =$	0	0	$-\lambda^{\beta}$	0	0	0	$+\lambda^{\beta}$	0

Routine for redistribution of R&D budget between innovative/imitative R&D, dependent on the development of the relative firm position in (before) the last year and the contemporaneous development of the R&D share.

$$\psi^{ly}_{i,tj} = \begin{cases} +\psi^{ly} \text{ für } N_{i,tj-1} < N_{i,tj-2} \\ -\psi^{ly} \text{ für } N_{i,tj-1} \geq N_{i,tj-2} \end{cases}, \quad \psi^{bly}_{i,tj} = \begin{cases} +\psi^{bly} \text{ für } N_{i,tj-2} < N_{i,tj-3} \\ -\psi^{bly} \text{ für } N_{i,tj-2} \geq N_{i,tj-3} \end{cases}$$

Routine for adaptation of mark-up, dependent on the development of demand in (before) the last year.

	if: $\iota^{\Delta tP}_{i,tj-3\to tj-2} < \iota^{\Delta c}_{i,tj-3\to tj-2}$			if: $\iota^{\Delta tP}_{i,tj-3\to tj-2} \geq \iota^{\Delta c}_{i,tj-3\to tj-2}$		
if: $\lambda_{i,tj-2}$ zu $\lambda_{i,tj-3}$	>	=	<	>	=	<
then: $\beta^{bly}_{i,tj} =$	$-\beta^{\lambda bly} \cdot \lambda^{\beta}$	0	$+\beta^{\lambda bly} \cdot \lambda^{\beta}$	$+\beta^{\lambda bly} \cdot \lambda^{\beta}$	0	$-\beta^{\lambda bly} \cdot \lambda^{\beta}$

	if: $\iota^{\Delta tP}_{i,tj-2\to tj-1} < \iota^{\Delta c}_{i,tj-2\to tj-1}$				if: $\iota^{\Delta tP}_{i,tj-2\to tj-1} \geq \iota^{\Delta c}_{i,tj-2\to tj-1}$			
if: $\lambda_{i,tj-1}$ zu $\lambda_{i,tj-2}$ if: $\lambda_{i,tj-2}$ zu $\lambda_{i,tj-3}$	<	=	= & =	>	<	=	= & =	>
then: $\beta^{ly}_{i,tj} =$	$-\beta^{\lambda ly} \cdot \lambda^{\beta}$	0	0	$+\beta^{\lambda ly} \cdot \lambda^{\beta}$	$+\beta^{\lambda ly} \cdot \lambda^{\beta}$	0	0	$-\beta^{\lambda ly} \cdot \lambda^{\beta}$
then: $\lambda^{\beta}_{i,tj} =$	0	0	$-\lambda^{\beta}$	0	0	0	$+\lambda^{\beta}$	0

	if: $\iota^{tP}_{i,t} < \iota_{i,t}$ $(\rightarrow \iota^{c}_{i,t} \geq \iota_{i,t})$	if: $\iota^{tP}_{i,t} \geq \iota_{i,t}$ $(\rightarrow \iota^{c}_{i,t} < \iota_{i,t})$
then: $\beta^{\iota}_{i,tj} =$	$-\beta^{\iota} \cdot \lambda^{\beta}$	$+\beta^{\iota} \cdot \lambda^{\beta}$

First part of the routine for redistribution of R&D budget between R&D for improvement of tP/c, dependent on

1. evaluated development of the relative tP-position, related to the relative c-position in the (before)last year and the contemporaneous development of the R&D share and
2. evaluation of current contribution of relative tP/c-position to current total firm position.

SCENARIO-DEPENDENT PARAMETER CONFIGURATIONS

1. Market growth	MP↑: $\zeta^{\vartheta(.)}$=10,000, with (.) = tP, c; η^{tP} and η^{p} unchanged MP→: $\zeta^{\vartheta tP}$= 100, $\zeta^{\vartheta c}$=10; η^{tP} and η^{p} unchanged MP↓: $\zeta^{\vartheta tP}$= 100, $\zeta^{\vartheta c}$=10, η^{tP} and η^{p} x2 for tP- and pregime, x 2.5 for tPpregime
2. Market entry barriers	B^{Max}=20 for maxMEB, 16 for mMEB, 12 for minMEB (in periods) ζ^{γ}=5 for maxMEB, 1 for mMEB, 0 for minMEB. δ=1.4 for maxMEB, 1 for mMEB, 0.6 for minMEB
3. Spillovers	ζ^{tP}=50 for maxSpo, 25 for mSpo, 10 for minSpo. ζc=500 for maxSpo, 250 for mSpo, 100 for minSpo.
4. Speed of environmental change	α=3 for maxα, 1 for mα, 0.1 for minα.
5. Competition of price- vs. quality	η^{tP}=10 for tPregime, 5 for tPpregime, 1 for pregime. η^{p}=1,000 for tPregime, 5,000 for tPpregime, 10,000 for pregime.
6. Number of firms in t=0	2 for 2U in t0, 6 for 6U in t0, 10 for 10U in t0.

SCENARIO-INDEPENDENT PARAMETER CONFIGURATIONS

$\lambda^{\vartheta}=0.2$	$\lambda^{\beta}=0.05$	$o^{(.)imi}=0.0005$	$o^{(.)back}=0.0005$
$\beta^{\lambda bly}=0.75$	$\beta^{\lambda ly}=1.5$	$\kappa^{\tau_x \rightarrow \tau_y}=0$	$o^{(.)inno}=0.0005$
$\beta^{\iota}=1$	$\pi=0.95$	$\zeta^{(.)ac}=0.001$	$\zeta^{ac}=10$
$\psi^{ly}=0.025$	$\psi^{bly}=0.0125$	$\zeta^{f}=1.05$	$\zeta^{l}=0.0005$
$\chi^{Min}=0.05$	$\iota^{(.)backpot}=0.5$	$\zeta^{\xi\tau}=1$	$\zeta^{\iota}=0.1\exp(1)$
$\omega=50$	$\nu=0.5$	$\zeta^{t}=10$	$\zeta^{up}=50$
$N^{Pot}=10{,}000$	$N^{Min}=100$	$\eta^{\xi}=1{,}000$	$\upsilon^{pot}=0.05$
		$t_{k=}5$	$K^{krit}=10$

SCENARIO-INDEPENDENT STOCHASTIC VARIABLES

$\varepsilon\left(u_t^{Max}, t\right)$=normal ($\mu= u_t^{Max}, \sigma= u_t^{Max} / \zeta^{t} \cdot t$)) $\rho_{i,t}^{\zeta}$=uniform[0;1,000] $\rho_{i,t}^{match}$=uniform[0;1]

$\iota_t^{(\cdot)back}$=normal $\left(\iota^{(\cdot)backpot}, \iota^{(\cdot)backpot}/10\right)$, mit $0 \leq \iota_t^{(\cdot)backpot} \leq 1$ $\vartheta_t^{(\cdot)back}$=normal$\left(\overline{\vartheta}_t^{(\cdot)}, \overline{\vartheta}_{,t}^{(\cdot)}\right)$

SCENARIO-INDEPENDENT INITIALIZATION OF FIRM-SPECIFIC VARIABLES

$tP_t^{back}=20$	$c_{t=0}^{back}=100$	$\lambda_{i,t=0}^{(\cdot)}=0{,}5$	$K_{i,t=0}$=normal(μ=10,000, σ=5,000)
$\chi_{i,t=0}=100$	$\psi_{i,t=0}=1$	$c_{i,t=0}=100$	
$tP_{i,t=0}=20$	$N_{i,t=0}=50$	$\lambda_{i,t=0}=0.5$	$u_{i,t=0}=50$

VII.2 APPENDIX B

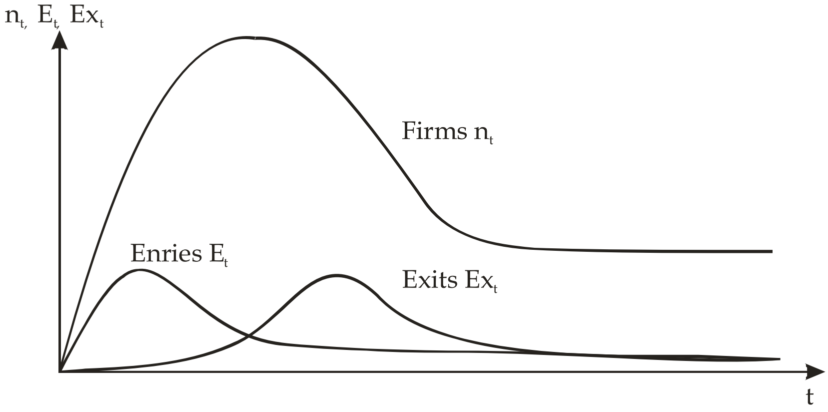
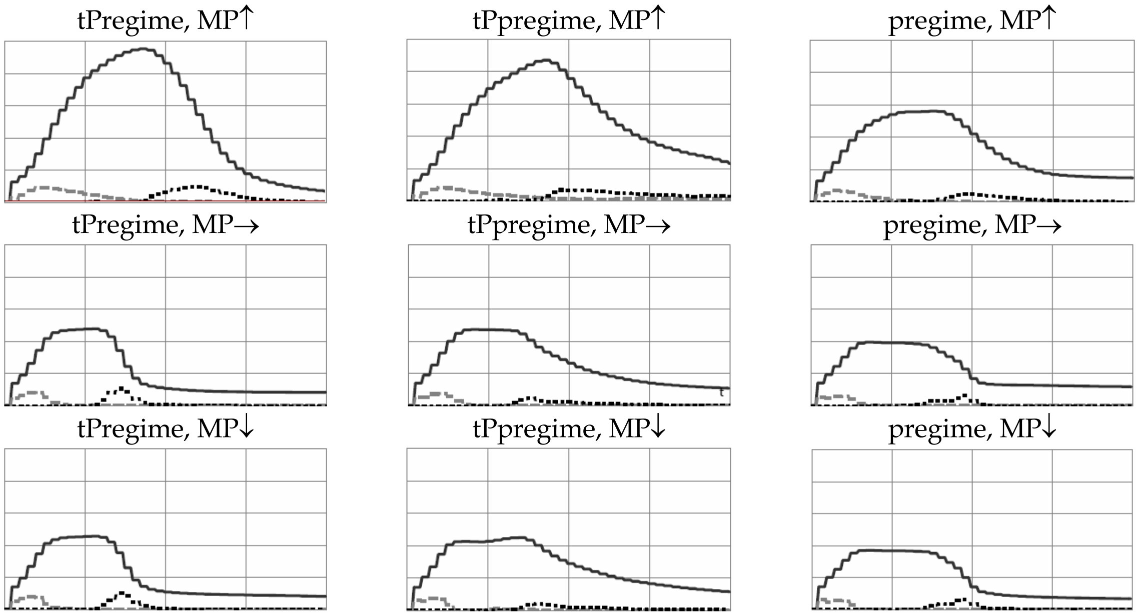


Diagram 1: Stylized Industry Life Cycle of the interdependent development of the number of firms, entries, and exits.



tPregime, MP↑

tPpregime, MP↑

pregime, MP↑

tPregime, MP→

tPpregime, MP→

pregime, MP→

tPregime, MP↓

tPpregime, MP↓

pregime, MP↓

Diagram 2: For all nine scenarios: mα, mSpo, 6U in t0, mMEB, Abscissa: t [0;160], Ordinate: [0;50]. ____ No. of firms n_t, __ __ No. of entries E_t, _ _ _ No. of exits Ex_t.

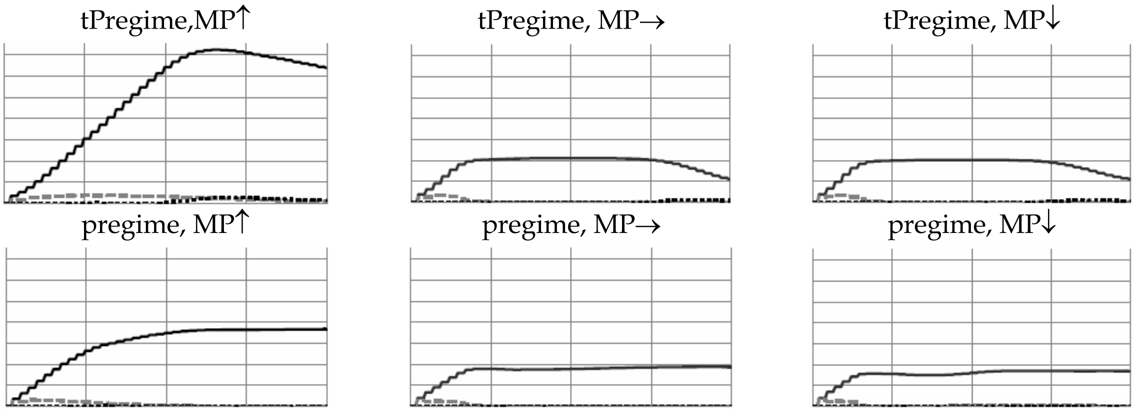


Diagram 3: For all six scenarios: minα, mSpo, 6U in t0, minMEB. Abscissa: t [0;160], Ordinate: [0;150]. ____ No. of firms n_t, __ __ No. of entries E_t, _ _ _ No. of exits Ex_t.

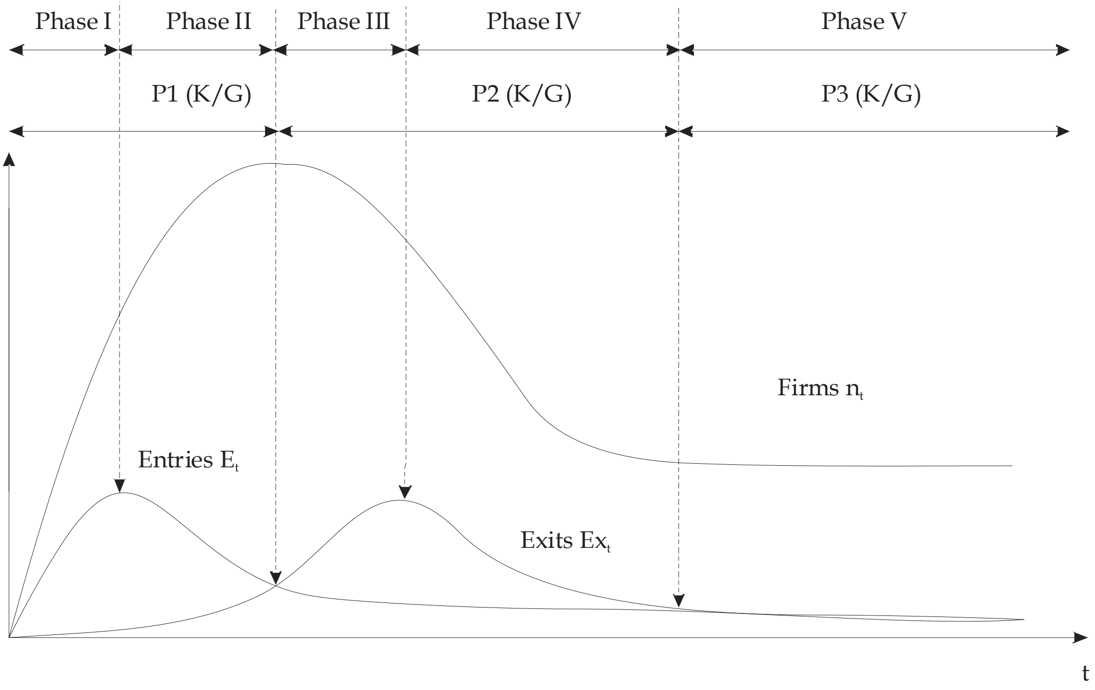


Diagram 4: Stylized Industry Life Cycle for the interdependent development of the number of active entries of new firms and exits of firms, based on the phase concept of Klepper and Graddy (1990) (P1-3 K/G) and the refined phase concept of this paper (Phases I-V).

MP	Re-gime	α	Entries E_t					Exits Ex_t					Net Entries (E_t-Ex_t)					Rate of Net Entries (E_t-Ex_t)/n_t				
			PI	PII	PIII	PIV	PV	PI	PII	PIII	PIV	PV	PI	PII	PIII	PIV	PV	PI	PII	PIII	PIV	PV
↑	tP	min	3.68	1.48	0.02	*	*	0.03	0.05	0.18	*	*	3.65	1.43	-0.15	*	*	0.24	0.03	0.00	*	*
→	tP	min	3.60	0.57	0.00	0.00	0.00	0.00	0.04	1.59	2.31	0.70	3.60	0.53	-1.59	-2.31	-0.70	0.31	0.02	-0.07	-0.13	-0.05
↓	tP	min	3.66	0.57	0.02	0.07	0.05	0.00	0.04	1.63	2.21	0.52	3.66	0.53	-1.60	-2.14	-0.47	0.32	0.02	-0.07	-0.13	-0.03
↑	tP	m	3.26	2.04	0.23	0.03	0.00	0.06	0.34	4.14	2.42	0.20	3.20	1.70	-3.91	-2.39	-0.19	0.24	0.05	-0.13	-0.25	-0.04
→	tP	m	3.05	0.95	0.03	0.02	0.04	0.02	0.11	4.40	1.12	0.03	3.03	0.85	-4.37	-1.09	0.01	0.29	0.05	-0.23	-0.13	0.00
↓	tP	m	3.09	0.89	0.03	0.04	0.04	0.01	0.09	3.93	0.99	0.06	3.07	0.80	-3.90	-0.95	-0.03	0.30	0.04	-0.22	-0.11	-0.01
↑	tP	max	2.98	1.84	0.30	0.06	0.00	0.10	0.36	4.85	2.84	0.02	2.88	1.48	-4.55	-2.78	-0.02	0.25	0.06	-0.18	-0.32	-0.01
→	tP	max	2.49	1.08	0.12	0.06	0.07	0.11	0.25	3.56	1.03	0.06	2.39	0.84	-3.44	-0.97	0.01	0.23	0.05	-0.19	-0.14	0.01
↓	tP	max	2.50	1.11	0.10	0.08	0.05	0.12	0.22	3.22	0.99	0.10	2.39	0.89	-3.12	-0.92	-0.04	0.24	0.05	-0.18	-0.13	-0.01
↑	tPp	min	3.30	1.61	*	*	*	0.03	0.05	*	*	*	3.27	1.55	*	*	*	0.22	0.03	*	*	*
→	tPp	min	3.17	0.64	0.00	0.00	0.00	0.00	0.04	0.75	0.90	0.12	3.17	0.60	-0.75	-0.90	-0.12	0.30	0.03	-0.03	-0.05	-0.01
↓	tPp	min	3.27	0.55	0.02	0.04	0.01	0.00	0.03	0.79	0.97	0.14	3.27	0.52	-0.77	-0.93	-0.13	0.32	0.03	-0.04	-0.05	-0.01
↑	tPp	m	2.78	2.17	0.42	0.28	0.09	0.44	1.40	2.81	1.73	0.47	2.34	0.77	-2.39	-1.44	-0.38	0.19	0.02	-0.08	-0.13	-0.06
→	tPp	m	3.00	0.99	0.01	0.00	0.00	0.00	0.08	1.71	0.76	0.09	3.00	0.91	-1.70	-0.76	-0.08	0.29	0.05	-0.09	-0.08	-0.01
↓	tPp	m	2.94	0.85	0.03	0.02	0.04	0.01	0.14	1.59	0.76	0.13	2.93	0.72	-1.56	-0.74	-0.10	0.29	0.04	-0.09	-0.09	-0.02
↑	tPp	max	2.71	1.83	0.67	0.29	0.03	0.46	1.03	4.42	1.90	0.15	2.25	0.80	-3.76	-1.61	-0.12	0.20	0.02	-0.14	-0.18	-0.03
→	tPp	max	2.81	1.35	0.05	0.02	0.02	0.04	0.28	2.86	1.28	0.04	2.77	1.07	-2.82	-1.26	-0.02	0.26	0.05	-0.15	-0.18	-0.01
↓	tPp	max	2.57	1.13	0.10	0.08	0.03	0.08	0.26	2.68	1.28	0.15	2.49	0.87	-2.58	-1.21	-0.12	0.24	0.04	-0.14	-0.15	-0.02
↑	p	min	2.95	0.69	0.01	0.00	*	0.02	0.04	0.04	0.00	*	2.93	0.65	-0.03	0.00	*	0.24	0.02	0.00	0.00	*
→	p	min	2.79	0.45	0.00	0.00	*	0.00	0.02	0.11	0.00	*	2.79	0.43	-0.11	0.00	*	0.28	0.02	0.00	0.00	*
↓	p	min	2.35	0.65	0.06	0.03	0.00	0.01	0.11	0.45	0.20	0.01	2.34	0.54	-0.39	-0.17	0.00	0.24	0.03	-0.02	-0.01	0.00
↑	p	m	2.81	1.13	0.08	0.11	0.06	0.02	0.15	2.17	1.21	0.09	2.78	0.99	-2.09	-1.11	-0.03	0.26	0.05	-0.09	-0.10	0.00
→	p	m	2.68	0.71	0.00	0.00	0.00	0.00	0.05	1.61	1.62	0.04	2.68	0.66	-1.61	-1.62	-0.03	0.28	0.04	-0.11	-0.19	-0.01
↓	p	m	2.67	0.63	0.02	0.02	0.01	0.01	0.09	1.85	1.18	0.03	2.66	0.54	-1.84	-1.16	-0.03	0.29	0.04	-0.14	-0.19	-0.01
↑	p	max	2.69	1.07	0.12	0.06	0.03	0.02	0.15	3.51	1.36	0.04	2.67	0.92	-3.40	-1.30	-0.01	0.26	0.05	-0.18	-0.18	0.00
→	p	max	2.57	0.74	0.02	0.01	0.00	0.02	0.13	2.18	1.30	0.02	2.55	0.61	-2.17	-1.30	-0.02	0.27	0.04	-0.16	-0.21	0.00
↓	p	max	2.30	0.86	0.13	0.07	0.03	0.11	0.41	2.13	1.09	0.04	2.18	0.45	-2.00	-1.02	-0.01	0.24	0.03	-0.15	-0.18	0.00

Table 1: No. of entries E_t and exits Ex_t, net entries (E_t-Ex_t), and rate of net entries (E_t-Ex_t)/n_t in the five phases of the Industry Life Cycle. For all 27 scenarios: mMEB, 6U in t0, mSpo. * Phases are not reached in the average of simulation runs of the scenario.

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