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Cyclicality of capital-intensive industries: a system dynamics simulation study of the paper industry

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Abstract

This paper provides a view on the cyclicality of capital-intensive industries that could add considerably to our understanding of how cycles in prices, profits and capacity come about. Previous studies of business cycles focus on macro-economic systems or on the agricultural sector. Causes for fluctuations are typically believed to be mainly exogenous in nature. We seek to extend the existing literature on industrial cycles by developing a model that incorporates endogenously generated cyclicality. A simulation model of the paper industry is developed, and validated on the basis of data for the US paper industry.

Keywords: Industry; Capital investment; Simulation; System dynamics; Inventory control; Just-in-time

1. Introduction

Cyclical behavior of economies and industries has attracted attention from scholars ever since the early 1930s when a large part of the Western world was hit by a severe depression. Business cycles can be described as "rhythmical alternations of prosperity, crisis, depression and revival" [1, p. ix] invoking a picture of music with a regular beat. Traditionally, studies of cycles focus on macro-economies or on agricultural commodity sectors [2,3]. This study intends to expand the literature by focusing on capital-intensive industries.

The course of firms and industries is, almost by definition, accompanied by times of prosperity and times of downfalls. As such, problems of cyclicality were already acknowledged in ancient times. The traditional cure has been to save resources during good times in order to survive the bad times. Although this recipe still holds for an individual producer, of say pulp and paper, the following pattern emerges on an aggregated industry level: if times are good the dominant wisdom is to invest in capacity and if times are bad, rationalizing is the strategy commonly followed. Rationalizing often goes hand in hand with the lay off of a large part of the labor force, which imposes costs on society. This underlines the importance of studying cycles in order to understand their emergence.

Moreover, the metaphor of "the seven good and the seven bad years" appears to characterize the dominant way of approaching cyclic problems: the people involved are not to blame for the downfalls, instead it is some incomprehensible or external power that causes them. The prevailing literature on causes and remedies for business cycles approaches cyclicality therefore from an external angle, attributing causes to forces outside the industry. Fluctuations in demand and raw material prices are considered as the major external causes. However, causes external to the industry merely provide a partial explanation. For example, the international paper and pulp industry currently suffers from a downturn in profitability while most other industries

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boom. In addition, from annual reports of companies in this industry, it becomes clear that most executive boards also adopt an external focus when explaining the situation to the public. For example, the following statement is taken from the annual report of a major European paper producer: "The paper industry was confronted with an unprecedented serious down cycle in the second half of 1995, as a result of which demand decreased and paper prices fell dramatically" (KNP-BT, [1] annual report 1997).

Historically, demand for paper rises with increasing prosperity (and both demand and production have risen in recent years), so obviously other factors are contributing to the industry's current performance. In this respect, overcapacity is generally blamed for slumps in the pulp and paper industry. A few interesting questions can now be raised: Why is overcapacity such a persistent factor in the pulp and paper industry? What causes firms to invest while knowing that adding extra capacity undermines industry profitability? How can we gain a deeper understanding of the processes leading to overcapacity? What is the influence of technological development on cycles?

This paper seeks to explore these questions with the use of simulation. Recent developments in social science suggest that simulation is a viable technique that can deal with the complexities of these questions in a more comprehensible way than more linear-like research methods. Specifically, growing computer power and user-friendly software with easy to understand symbol-steered-language makes simulation feasible for practitioners in the social sciences that would normally not consider simulation as an analytical tool [33].

This paper is organized as follows. First, we explain why simulation and specifically the system dynamics perspective is used here. Then, the industry under study—the pulp and paper industry—is described. Third, we will briefly describe the models found in the literature and explain the choice of a model developed by Meadows as our starting point. Subsequently, the original model will be adjusted and validated. Finally, the influence of new process technology on cycles is explored with the model.

2. Simulation and system dynamics

The main arguments for using system dynamics simulation technique are as follows. First, systems thinking [4] and more specifically feedback thinking [5] appears to enrich the ability to communicate meaning by the use of symbols that picture relationships between the most important elements in a system [6,7].

Second, simulation allows the researcher to test a hypothesis quantitatively in a way that mathematical methods do not allow for, due to analytical complexity that increases if the number of relationships in a model increases. Of course, econometric methods are used in estimating parameters in relationships. Specifically, system dynamics simulation is a powerful tool that allows for multiple layer simulation in a way that is very user friendly; moreover, it keeps the parts of the system and the way they are connected visible.

Finally, system dynamics rests on two assumptions that make it a useful tool for our research purpose. The first assumption is that behavior is caused by the underlying structure of the system in which the behavior takes place and thus the unit of analysis should be the structure rather than the behavior itself. Secondly, due to interactions between several parts of a system one should try to understand behavior in a systemic way. This understanding can only be gained by studying the whole of relevant parts and their connections within a system [8,9].

The last argument in itself is not enough to justify the application of simulation tools from system dynamics. It merely adds to the previous two arguments. As with any other form of simulation, the outcomes of a simulation study should be evaluated in terms of the plausibility of its outcomes and within the confines of the theory-driven assumptions underlying the model.

3. Cyclicality of the paper industry

Our main interest is in understanding the forces that drive cyclicality in capital-intensive industries. The paper industry serves as a good example of the industry cycle phenomenon because it is regularly hit by severe depressions.

The paper industry is part of the broader forestry industry system that starts with forestry and ends with different buyers from stationary retailers to printing and packaging firms. The customer base of most segments in the paper industry involves professional buyers who evaluate the products on quality and price. Since quality is rather homogeneous across a broad range of different suppliers, price is the main decision criterion. The paper industry, as defined here, also includes the production of pulp and board. Profitability and capacity utilization in the international paper industry show strong cyclical tendencies that are found to be weakly predictable. This aspect of the industry seems contradictory because aggregate production as a proxy for demand rises steadily over the years [10].

The population in the western world has grown with about 5 percent over the period 1978–1997, while paper consumption has increased with about 50 percent in the same period (source: PPI). Fig. 1 shows the development of capacity utilization and profitability of the international paper industry. It shows that profitability, in terms of the average return on assets of the 150 largest paper and pulp producers, goes up and down with the operating rates. The instability of the return on assets (ROA) is a reason for concern for the actors in this industry.

[1] KNP-BT: the result of a merger between the Royal Dutch Papermills (Koninklijke Nederlandse Papierfrabrieken) and Bührmann Tetterode (BT) a trading company.

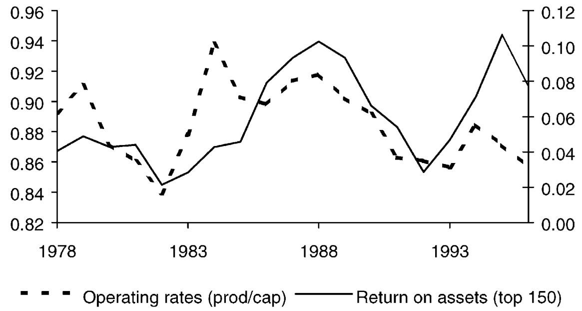

Fig. 1. Capacity utilization (left Y-axis) and return on assets of the top 150 producers, 1978–1996 (source PPI).

Apparently, these cycles are supply driven and aggravated by demand fluctuations. That is, too much production capacity enters the market in batches after periods of relative profitability, because producers tend to make capital investment decisions approximately at the same time. Evidently, the fact that most actors decide to invest simultaneously is not a sufficient condition to explain cyclical behavior. Zavatta [11] argues that producing paper goes with large economies of scale, meaning that the decision to invest implies a certain minimum size for a plant. That is, investment costs per unit of output decline markedly with size, mainly as a result of indivisible resources (e.g. computerized control equipment). The economies of scale differ somewhat depending on the paper grades produced. Specialty paper, for example, benefits less from scale economies than newspaper paper because customized orders are mostly smaller than an efficient machine run [11]. Thus, producers collectively invest more than growth in demand justifies, feeling forced to invest when a competitor does so. Then, due to the highly capital intensive nature of the industry, individual companies will do their utmost to "keep the machines running". Hence, in times of overcapacity, paper producers try to sell their products with prices going down until they barely cover the variable costs. The buyers, of course, are aware of this situation and are very price sensitive; apparently, there are no major differences in paper grade quality between producers.

Two structural features of the industry therefore appear to drive a pattern of collective behavior that tends to be destructive. First, as we have seen, producing pulp and paper in a competitive manner requires significant *scale economies* and thus large amounts of invested capital. Second, the industry is characterized by delays of 3–5 to five years between the investment decision and the moment the new capacity is available for actual production. These two structural features constitute a prisoner's dilemma situation: individual firms may be well aware of the industry's structure, but feel trapped or forced to continue their investments, fearing that not complying to the "rules" will lead to even more severe future losses. Moreover, due to the delay between the investment decision and actual capacity increase, cause and effect are often difficult to address and thus easily misunderstood [8,12].

In trying to find a solution for these cycles in performance in a fragmented capital-intensive industry, concentrating market power by integrating individual businesses is traditionally regarded as an interesting solution. In this respect, market power in the world-wide paper industry has indeed become more concentrated in the last decade: the C-10, the market share of the 10 largest producers among the top 150 producers (covering approximately 60 percent of world sales in the paper industry), has been increasing from 0.29 in 1988 to 0.32 in 1993 and 0.34 in 1997 (source: PPI). The largest paper firm—born from a recent takeover of US-based Champion by International Paper—currently has a market share of about 6 percent of the total sales of the 150 largest producers. These figures also show that overarching market power of a few producers is presently absent, which basically impedes any attempt at market co-ordination.

4. Starting point: Meadows' model

Traditional cycle research focuses on the macro business cycle [1,2,13–16]. These studies focus on real time series of monetary data. The basic idea is that the cycle originates in discrepancies between exogenous supply and demand of factor inputs (capital and labor). Another strand of literature [12,17–21] deals with modeling an economy and attributing the existence and proliferation of cycles to, for example, instabilities of ordering behavior (information delay structure), the bounded rationality of the decision takers, and misperception of the physical feedback structure. These models basically consist of two or more interlinked sectors, and can explain the phenomenon without exogenous shocks. Shocks do exist, but merely aggravate the cycle rather than inducing it.

Few studies have been published in the area of industry cycles. Zhang and Buongiorno [22] explain the addition of capacity in the pulp and paper industry by referring to Tobin's q-theory on what drives investment. Zhang and Buongiorno's article starts from a neoclassical view on investment, seeking proxies of complete markets. The drawbacks of this model are that, first, depreciation of capacity is endogenously determined, leading to economic life spans of 4 years to infinity, and second, no interaction between the productive and consumptive sector takes place.

Meadows developed a model that explains cycles and investment decisions in agricultural commodities [3]. Meadows' work is a basis for other system dynamics market models e.g. [23]. Meadows' work follows a system dynamics perspective, taking a more behavioral perspective than is typically done in the neoclassical literature. The model of Meadows [3] is, however, not developed for capital-intensive industries but for agriculture. Other drawbacks are that the model assumes fixed consumption per

Table 1
Summary of the assumptions made by Zhang and Buongiorno [22] and Meadows [3]

Assumptions	Zhang and Buongiorno [22]	Meadows [3]
Investment	Based on projected cashflows/Tobin's q	Based on expectation of prices
Price	Exogenous to the model	Endogenous
Consumption	Exogenous	Dependent on needs per capita and price
Price/demand effects	Not accounted for	Reinforcing cyclical effects

capita and its investment function is based on an expectation of price only.

The model of Meadows [3] was nevertheless chosen as a starting point for our study because the assumptions in this model are much richer than those made by Zhang and Buongiorno [22], whereas the drawbacks of Meadows' model can probably be overcome. Table 1 summarizes and compares the key assumptions made by Zhang and Buongiorno [22] and Meadows [3]. More specifically, the advantages of Meadows' model in the context of this study are:

1. the parameters that drive investment behavior are directly observable,
2. fewer exogenous inputs are required, and
3. it allows for alternative policy testing.

The remainder of this section gives a more detailed description of Meadows model [3], with several extensions and references to more recent literature. The following two assumptions, which are well grounded in economic theory, are at the heart of Meadows' model. First, producers are motivated to maximize profit, and their decisions to invest are guided by this principle. The producer focuses on expected prices as a predictor of profits, and as a predictor of desired capacity. Second, consumers are believed to need a certain amount of the product, but tend to look for substitutes as prices get higher; they will fill up extra stock or substitute other products with paper products if prices get lower [3].

The general *causal structure* of Meadows' model is depicted in an informal way in Fig. 2, using the notation conventions of system dynamics. This figure makes clear that the system consists of a producer, a market and a clearing mechanism. Producers deliver their products to one central distributor that tries to maintain the balance between inventory level and consumption by adjusting the price level so that inventory coverage—the amount of inventory to expected consumption—satisfies its criteria to be able to deliver promptly (note that this process is Walrasian in nature). The market buys an amount of the products at a certain price; if the model is in equilibrium, the amount consumed per capita is equal to the equilibrium per capita consumption.

Key elements in Meadows' model are *delays*. Delays arise because it takes time for data in the form of indicators to be transformed into information that can be used for decision-making. Delays operate in technical as well as so-

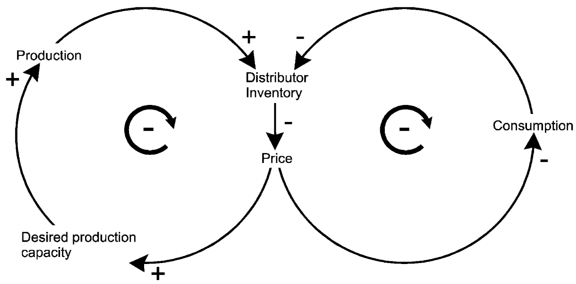

Fig. 2. Causal loop structure. Working from any variable chosen as the starting point, the polarity of the shown loop is established by tracing through the effects each link until a circuit is completed. If the net effect is to reinforce an initial change in the variable chosen as the staring point, the loop is "positive" and is denoted by "+", whereas the effect is counteracted, the loop is "negative" and is denoted by "−".

cial systems, and are incorporated in the model in places where one can expect such delay structures.

Meadows uses several *curvi-linear* functions that determine price, per capita consumption and desired capacity. This means that the functions are of a monotonically increasing or decreasing nature. The logic for the form of these curves is highly similar and therefore only the "per capita consumption requirements" will be highlighted as an example. Economic theory suggests that consumption is a decreasing function of price: the higher the price, the lower the amount consumed. We are thus used to graphs that display only the linear parts of this relationship and we take this linearity for granted for computational reasons. Nothing is wrong with this assumption of linearity as long as we are conscious of the fact that this linearity holds for only a certain range of prices. For example, the relationship between price and consumption is as follows. Certain amounts of products will always be bought, no matter how high the price is. Conversely, a maximum amount of products will be taken no matter how low the price is.

Expectations of certain key indicators play an important role when taking decisions. In Meadows' model the inventory holder makes projections of the amount of consumption in the next period and producers try to estimate demand or prices for some future time in order to adjust production and investment. The expectation functions used have been tested both empirically [3] and experimentally [12,21,24]. These studies found that the adaptive expectation form was the functional form that best fitted the data. An adaptive expectation means that the projected value of the indicator is a combination of its past values in which the most recent ones get the highest weight. Put formally, the expected price at time t is defined as

$$\bar{P}_t = bP_{t-1} + (1-b)\bar{P}_{t-1}, \quad 0 \leqslant b \leqslant 1. \tag{1}$$

In line with the system dynamics literature, Meadows [3] uses a certain *symbolic* language that has been developed to represent systems. This language involves so-called material stocks and flows and informational flows. An overview of Meadows' model, using the stock and flow language, is given in Appendix A.1, where flows of goods are represented by double lined arrows, information by single lined arrows, and state variables (stocks) by rectangles.

5. Modeling the paper industry

This section contains a validation process in which we seek for anomalies in the results and correct them by adding apparently more viable heuristics cf. [25,26]. Note that this process is very similar to searching for falsifiable explanations of reality. Our basic hypothesis in this process is that the model is able to predict reality well. Rejecting the hypothesis leads to examining the assumptions and where needed, plausible adjustments should be looked for.

A minor adjustment to the original model is in the consumption function. Meadows believed consumption to cycle around a stable per capita consumption [3]. For food products, this is quite plausible: there is, for example, simply a maximum amount of grain that a person can consume. However, per capita consumption of paper and pulp has risen 2 percent annually over the past 40 years (source: PPI). Moreover, given the high current growth in per capita paper consumption for Eastern and Southern Europe and the Asian continent—which are expected to remain high in the next 10 years—the overall growth rate can be assumed to be around 2 percent. We therefore included a 2 percent growth factor influencing per capita consumption requirements in the model.

Another adjustment is in the area of investment decisions. The investment decision for agricultural production is a recurrent one, that is, investment decisions are taken every 3–6 months: land produces crop once or twice a year. In the paper industry, it takes roughly 3–5 years to construct a papermaking machine, in which huge amounts of capital are invested. With regard to the original model of Meadows, this implies an increase of the transfer delay between the initiation of new capacity and the actual capacity change from 3 to 36–60 months. We also will introduce an economic life span of the machinery, which is estimated to be around 25 years.

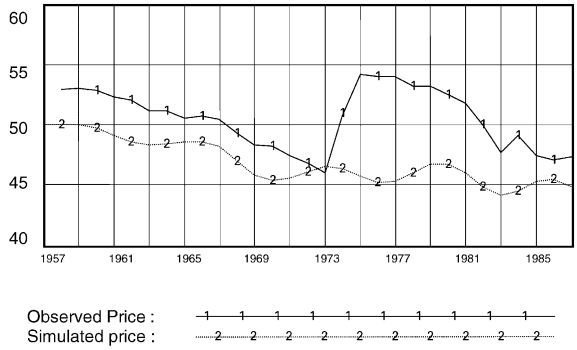

Fig. 3. Observed vs. simulated price.

5.1. Validation of the model: price determination

We now have a model that is extended and adjusted in three ways (exogenous growth factor for per capita consumption, increase of delay between initiation of new capacity and actual capacity increase, introduction of economic life span). In attempting to validate the model, we use the same data Zhang and Buongiorno [22] used. These are data for USA only, gathered from the Bureau of Census (see Appendix A.3).

If we use the real capacity development to drive the simulation, the simulated price can be compared with the actual price development. Fig. 3 shows the results. We have decided to provide some statistical information, although Sterman states that "… there is ultimately no substitute for plotting the simulated and actual data together" [9, p. 875]. Until 1974 (year 16), the year after the sudden surge in oil prices, the simulated and observed price move nicely together. After 1974, however, a pattern emerges that cannot be explained by the model. As almost all industries faced a jump to a higher price level due to the effects of the oil crisis, the paper industry also suffered from this more or less exogenous macro-economic shock [27]. We used OLS regression to determine to what extent the observed data can be explained by the simulated data, taking the oil crisis into account by means of a dummy variable, leading to an adjusted R^2 of 0.75. Then, Theil's inequality statistics have been calculated as to decompose the mean squared error between simulated and data points into bias, unequal variation and unequal covariation [9]. Theil's unequality statistics indicate that 64 percent of the 6 percent mean absolute percent error can be ascribed to bias, 4 percent to unequal variation and 31 percent to unequal covariation. The combination of the graphical and statistical results suggests that this part of the model provides a good foundation to explore it further.

5.2. Validation of the model: capacity determination

Meadows' investment function only deals with a prediction of the price level and the accompanying level of

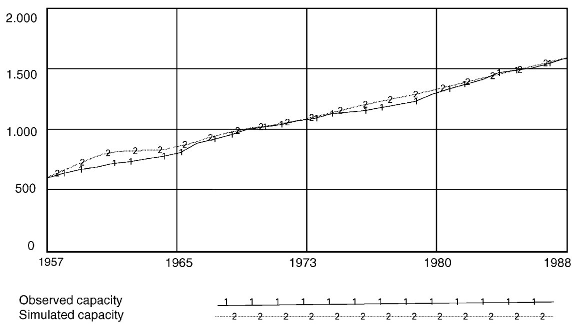

Fig. 4. Observed vs. simulated capacity.

desired capacity. This heuristic is built around the idea that a gap between desired and actual capacity triggers decisions to add capacity. The investment decision function takes into account current capacity, capacity under construction (capacity being transferred) and desired capacity and is subject to the construction time and the time to take the decision (see Appendix A.1). For the paper industry, the construction time is estimated to be between 3 and 4 years and the time to take the decision is assumed to be between one year and one and a half year (due to the massive required funds allocated to new capacity).

Initial simulation runs in which we used observed price as an input to drive the simulation (of capacity determination sector of the model), resulted in simulated capacity which increasingly diverges from the observed capacity. This initial result can be explained from the fact that the original investment function does not take growth of per capita demand into account (see Appendix A.1). We might infer from these findings that in a (slow) growth market, price is not the only factor directly determining investment in new capacity. In addition to the expected price level, demand expectations (predictions) may be fueling investment. We, therefore, assume that the desired production capacity is determined by the expected consumption and the difference between the expected price and an equilibrium (break-even) price, on the basis of which the producer generates (or fails to generate) investment funds for new capacity. Simulation on the basis of observed price as input yields the results for simulated vs. observed capacity given in Fig. 4. Theil's inequality statistics indicate that 54 percent of the mean absolute percent error of 4 percent can be ascribed to bias, 16 percent to unequal variation and 31 percent to unequal covariation. The adjusted R^2 of 0.996 together with the graphical representation suggests the extended investment segment of the model explains the observed capacity development rather well.

5.3. The influence of new process technology

Having validated the extended model, we can now use the model to determine in what way technological change affects the volatility and the duration of cycles in the paper industry. Particularly, the introduction and diffusion of new process technology, such as CAD/CAM and just-in-time inventory management, in all likelihood have been influencing cyclicality in the paper industry. But how exactly? The model developed in the previous section can be used to find (preliminary) answers to this question.

In the context of the extended model for the paper industry (Appendix A.2), the introduction and diffusion of new process technologies particularly affects two model elements:

- Capacity transfer delay (CT): this is the delay between the investment decision and the moment the new capacity actually comes available for production. Particularly, as a result of new design and development technology (such as CAD), used by suppliers of pulp processing and paper production machinery, this delay can be assumed to have decreased in the last 10–15 years.
- Desired inventory coverage (DIC). Basically, this is the rate of inventory to consumption coverage that the producer prefers to maintain. The gradual diffusion of (JIT) on-line information systems between producers, distributors and retailers can be assumed to have decreased the inventory/demand coverage, also because smaller inventories reduce cost per unit. The development of e-commerce and e-business tools will probably reinforce this trend in the nearby future.

Table 2
Effects of decreasing two parameter values on cycle amplitude and cycle time

	Amplitude	Cycle time
Capacity transfer delay (CT)	Decreasing	Shortening
Desired inventory coverage (DIC)	Increasing	Shortening

In order to determine what the influence of (gradually) decreasing these parameters is, from their respective base values (DIC = 10 percent and CT = 2.5 years), we performed a number of simulation runs. In the simulation runs, we gradually decreased the value of one of these parameters. The results are summarized in Table 2. Shortening the capacity transfer delay (CT) leads to smaller average amplitude but shorter cycle times. By decreasing the relative inventory level the producer wishes to maintain (DIC) which reinforces the amplitude of cycles and also shortens cycle time.

The results for CT suggest that investments in technologies such as CAD/CAM can decrease cyclicality, because it allows producers to adapt their production capacity more quickly (less delays as result of time lost in building machines, plants, etc.). The results for DIC confirm the intuitive wisdom that technological developments tend to destabilize capital intensive industries. No individual producer can withdraw from investing in this area because competitive forces impose the diffusion of new logistic technologies. But at the same time, these technologies reinforce cyclicality.

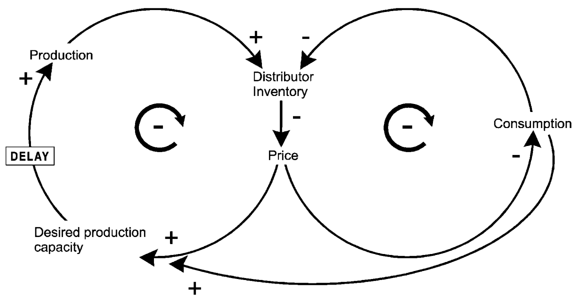

Fig. 5. Causal loop structure adjusted for direct demand influences.

6. Conclusion and discussion

The conventional way of looking at cycles in capital intensive industries is to attribute these cycles to mainly external causes, such as raw material prices and demand fluctuations. We propose to change this perspective towards attributing causes internal to the industry. On the basis of a model developed by Meadows for the agricultural industry by means of system dynamics modeling techniques, an adjusted and extended simulation model for the (capital intensive) paper industry was developed. The most important adjustments were regarding the (much longer) delay between investment decisions and the moment new capacity comes available for production, and the role of demand expectations in investment decisions. The general causal structure of the extended model is depicted in Fig. 5 (compare with Fig. 2).

The model was validated with data from the US paper industry, first, for the price determination sector of the model, and second, for the capacity determination sector. Overall, the results of these validation processes were good. Finally, the influence of the introduction of new process technologies was simulated by means of the validated model. These simulation runs showed that certain technologies tend to reinforce cyclicality in capital-intensive industries, in terms of both the amplitude and the period of cycles, whereas others do not.

These results should be assessed in the context of the limitations of the model. For example, a perfect supply side monopoly has been assumed. Another limitation arises from the assumption that capacity maintenance is similar up- and downwards. In practice this process will probably be asymmetric: capacity will be easier added than decreased for capacity once built requires little maintenance. Instead, individual producers will vary capacity utilization to buffer price differences. It might thus be useful to regard capacity as defined in this model as capacity in use.

A more fundamental limitation of this model arises from the nature of any model as a limited, simplified representation of the real world. Thus, some authors argue that validation or verification of models, in the sense of establishing truth, is impossible [9,17,26,28]. Regardless of whether one agrees with this position, models seem to be most useful when they are used to challenge existing formulations, rather than to validate or verify them [29].

Overall, this study results in a model which describes and simulates how capital intensive industries generate their own volatility. Thus, this study provides a challenging view on industrial cyclicality, possibly implying other than traditional cures to business cycles. The implications for industry policy have not been discussed in detail in this article. One clear implication is that governmental agencies stimulating the application of new process technology should do so with caution, because our model suggests that certain kinds of technology reinforce cyclicality in capital-intensive industries, whereas others do not.

Cyclicality of other capital-intensive industries can be examined in future studies. In this respect, industries such as chemicals, primary metals and civil aviation have a similar structure (significant scale economies, delay structures) and also suffer from cyclicality, regardless of the high concentration ratios in some of these industries [30,31]. Two questions should guide further research for capital intensive industries: (a) to what extent should concentration of supply rise in order to have a dampening effect on price volatility, and (b) what other strategies can be applied by producers when influential coordination cannot be attained? These questions can be explored in the same manner, by means of system dynamics simulation modeling, as was done in this study.

Acknowledgements

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Appendix A.

A.1. Stock and flow representation of the original model (source: Meadows [3])

Fig. 6 shows the original model as proposed by Meadows [3]. Within the system dynamics school, a symbolic language has been developed to represent systems. Without going into much detail, the model represents material stocks and flows and informational flows. To explain stocks and flows, it is instructive to use a bathtub as a metaphor. The tub is the container able to hold a certain amount of water, the amount of inflow and outflow of water determines the level of water in the tub. To set the valves, the person taking a bath needs information on the current level and needed level. This example can be seamlessly transposed to the level of capacity. For an investment

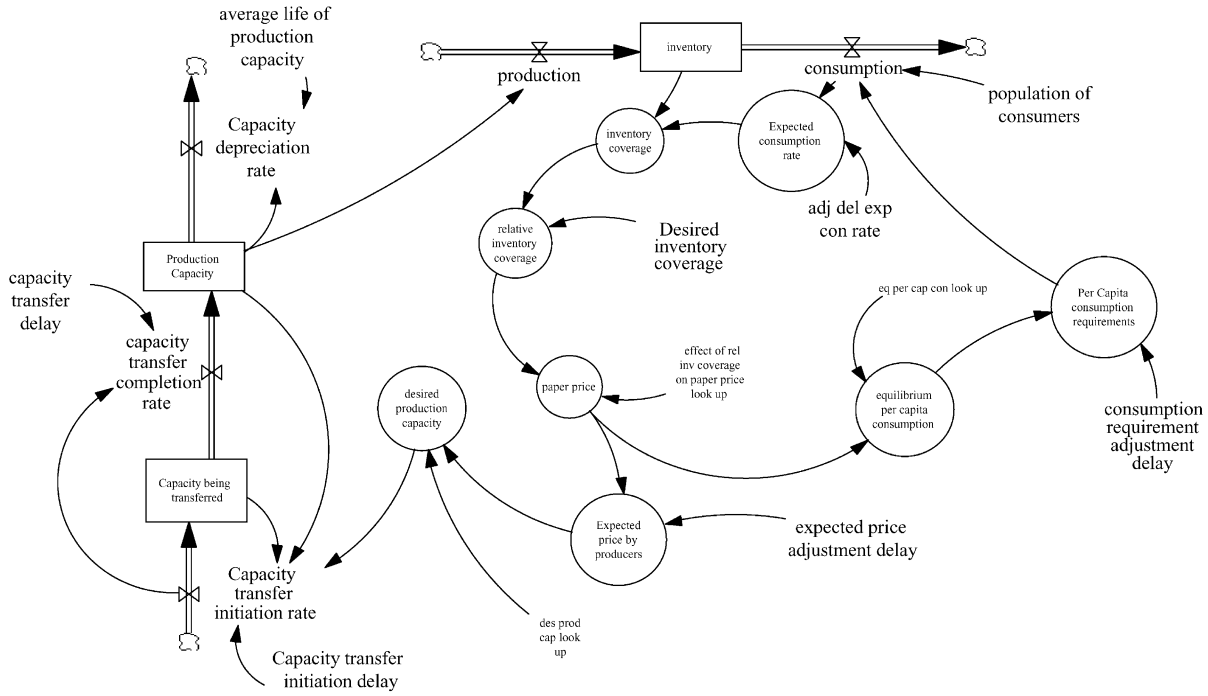

Fig. 6. Stock and flow representation of the basic model (adjusted from Meadows [3]).

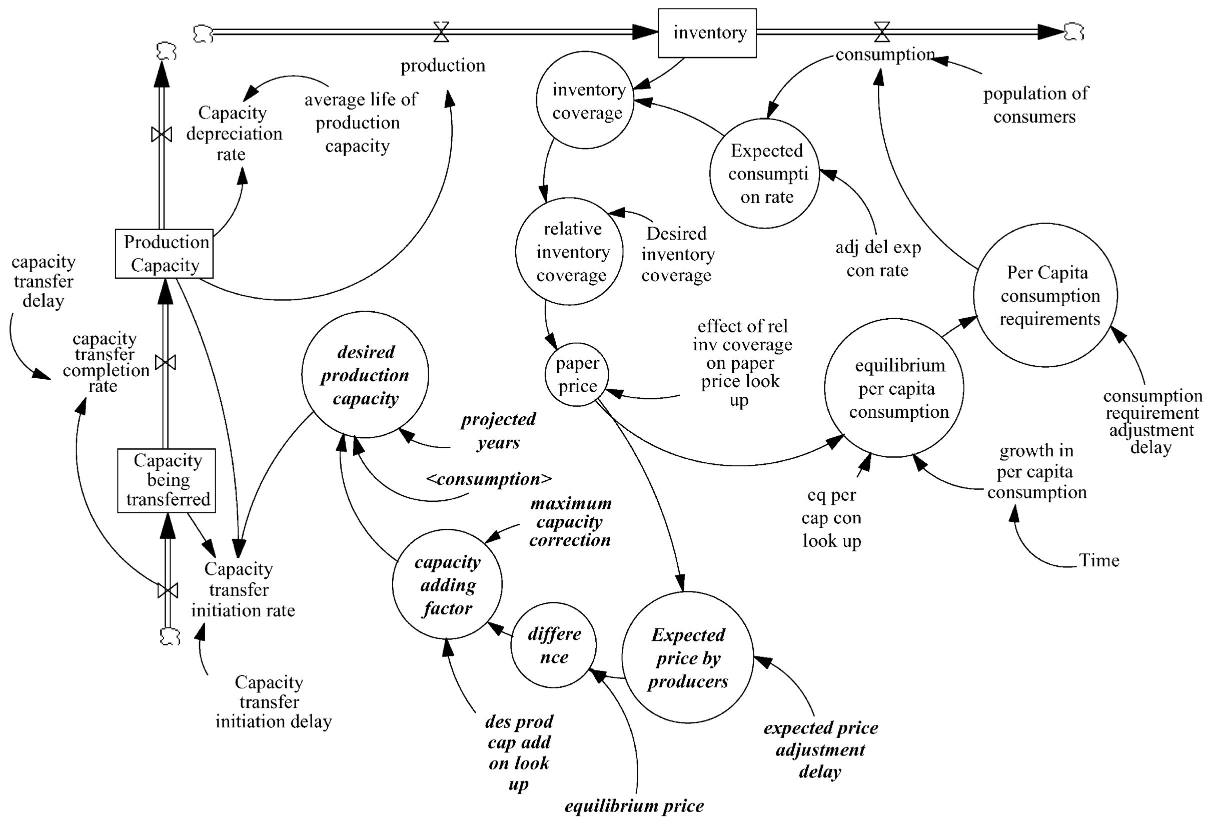

Fig. 7. Stock and flow representation of the extended model (extensions bold and in italics).

Table 3
Data for the US paper industry (source: Zhang and Buongiorno [22])

Time	Capacity	Price[a]	Time	Capacity	Price[a]
1957	15185	—	1973	27621	6,441441
1958	16030	7,404844	1974	28532	7,099391
1959	16825	7,42268	1975	28922	7,583643
1960	17410	7,398649	1976	29210	7,557118
1961	18134	7,324415	1977	29831	7,557756
1962	18531	7,284768	1978	30460	7,453988
1963	19149	7,156863	1979	31179	7,451791
1964	19662	7,16129	1980	32659	7,342233
1965	20499	7,079365	1981	33706	7,249725
1966	22423	7,098765	1982	34665	6,994819
1967	23167	7,065868	1983	35675	6,676707
1968	24147	6,896552	1984	37106	6,871992
1969	25257	6,757493	1985	37581	6,644981
1970	25806	6,752577	1986	38014	6,587591
1971	26270	6,641975	1987	39080	6,628521
1972	27156	6,555024	1988	40211	7,032967

[a]adjusted for inflation.

decision, a producer needs information on the desired level of capacity, the current level of capacity, and the capacity that is already under construction. The sketch of the model clearly distinguishes between flows of goods (double lined arrows) information (single lined arrows) and containers (rectangles).

The model makes use of curvi-linear functions in determining price, per capita consumption and desired capacity, as has been noted in the text. We refer to these non-linear (but monotonically increasing or decreasing) relationships as look-ups and these are defined in the list of equations as pairs in a grid.

Some abbreviated variables:

Adj del exp con rate
= adjustment delay for expected consumption rate
Des prod cap look up
= desired production capacity look up
Efffect of rel inv on paper price look up
= effect of relative inventory coverage on paper price look up
Eq per cap con look up
= equilibrium per capita consumption look up

A.2. Extended model for the paper industry

The following figure shows the extended stock and flow diagram for the paper industry. The added parts are depicted bold and in italics. Variables in brackets ⟨⟩ indicate replication of original variables for representational purposes only (Fig. 7).

des prod cap add on look up
= desired production capacity addition, based on a deviation of the projected price to the equilibrium price.

A.3. Data for US paper industry (Table 3)

Uncited Reference

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