A Simple Supplier-based Market Model Offering Rich Dynamic Potential

Christian Iniotakis

Ulm University of Applied Sciences, Prittwitzstraße 10, D-89075 Ulm, Germany; *christian.iniotakis@thu.de*

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Abstract. This work introduces a (toy) market model that relies on a simple, individual decision-making behaviour of suppliers: Which fraction of the current sales to spend for the next production? Within the model, this behaviour - together with characteristic properties of both the market and the particular cost setting - is decisive for the supplier's long-term existence on the market as well as the resulting market dynamics in general. Eventually, such a market can vanish, become stationary, exhibit market cycles or even go chaotic.

Introduction

Markets exist in an abundance of variations and are prime examples of complex systems in economy, e.g. [1, 2, 3]. As a basic feature, real markets as well as typical approaches for modelling them involve suppliers, demanders, and some type of interactions resulting in trading activities, e.g. [3].

From the simulation perspective, it is quite common to work with rather simple (toy) market models, which - despite their simplicity - still allow for qualitative insights into market behaviours, and are also helpful in the course of student education, e.g. [2, 4].

This work introduces a model which is particularly simple, while offering a suprising variety of inherent dynamic market patterns. The model only applies to some specific types of markets relying on certain assumptions and restrictions as briefly described in the following.

1 Model Assumptions

The market under consideration occurs in discrete time steps t and enables the trade of one particular, indifferentiable, commodity-like good. In other words, units from different suppliers are all valued to be of the same quality from the demanders' perspective.

Moreover, once produced all units need to be directly sold, e.g. they are perishing goods or there are only negligible buffering or storage options. All market participants are fully aware of the overall situation, such that the price P per sold unit is the same for every unit and solely depends on the total number (or quantity) Q of units sold at the market, also referred to as market size in the following.

The suppliers on this market are explicitly modelled, with each supplier n producing an individual number q_n of units. The production of each supplier is assumed to be fully scalable, just based on individual, but constant production costs c_n per unit, and without relevant dead time, i.e. any delay caused by actual production times can be neglected.

In contrast to the suppliers, the demanders are only taken into account in an aggregated way in form of a linearized demand curve, determining the resulting unit price $P(Q)$. The demand curve has a negative slope - the larger Q, the lower the unit price P - and is fully characterized by two parameters denoted as Q_{max} and P_{max} in the following. Q_{max} is the particular market size for which the unit price even drops to zero, commonly referred to as saturation quantity. The prohibitive price P_{max} is the maximum price per unit to be achieved in the limit of minimum supply $Q \to 0$.

Probably the most crucial feature of the model is how to implement the dynamical behaviour: How do suppliers decide about their next, future productions $q_n(t+1)$ based on the current market situation at time t or even the past?

For example, a rather simple, supposedly rational approach of an individual production increase or decrease - depending on the current market being profitable or not - leads to a closed simulation model with typical characteristics also found in real markets of that type, but is not in the scope here [5].

The model presented in this work, however, relies on an approach even simpler. After selling all units, a supplier just uses an individually chosen 're-investment' percentage ε_n of the sales for the production of the next units and simply takes the remainder as his or her personal profit, as sketched in Fig. 1.

This model assumption certainly is debatable, nevertheless some particular properties should be pointed out. Firstly, such a supplier accepts a profit that directly scales with the current sales, which is not as far-fetched as it might seem at first glance. Secondly, following this behaviour offers the attractive side aspect of never bearing an individual loss, at least in principle, which is rather hard to achieve on such a type of market otherwise.

Moreover, such a simple procedure of decision-making neither requires effort nor access to particular market or competitor information.

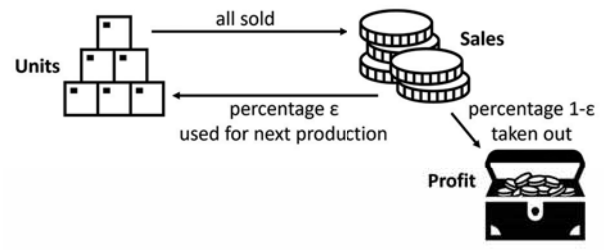

Figure 1: Sketch of simple supplier behaviour: After selling all units, a fixed percentage ε of the sales is re-used for producing the next units, while the remainder is taken out as profit.

2 Model Equations

Each supplier n starts with an initial number of units $\mathbf{q}_n(0)$. Here and in the following, quantities depicted in bold style are normalized to Q_{max} for convenience and therefore dimensionless.

The resulting dynamic behaviour is determined by the time stepping equations

$$\mathbf{q}_n(t+1) = r_n \cdot \mathbf{q}_n(t) \cdot (1 - \mathbf{Q}(t)) \tag{1}$$

together with the total market size

$$\mathbf{Q}(t) = \sum_n \mathbf{q}_n(t). \tag{2}$$

The individual parameter r_n is dimensionless, assumed to be constant over time and simply given by:

$$r_n = \varepsilon_n \cdot \frac{P_{max}}{c_n}.$$

Here, as introduced above, ε_n is the 're-investment' percentage, c_n are the production costs per unit, and P_{max} is the prohibitive price.

While the latter factor is identical for all suppliers and represents a property of market and good, the production costs depend on various aspects, such as purchasing and labour costs, the involved production technology as well as the excellence in applying it, etc.; typically, this factor is not too different between similar supplier settings.

In contrast, the factor ε_n is a fully individual parameter that can simply and freely be chosen without any restriction. In the following, the constraint $0 < r_n < 4$ is applied for all involved suppliers which ensures the total market size to stay within regular bounds $0 < \mathbf{Q} < 1$ at all times. As a consequence, the market can go on forever with both unit prices and quantities always positive.

3 Some Results

Competition

The model turns out to be highly competitive in the sense of a tough selection of suppliers surviving on the market in the long run.

As a key result, this existential issue is purely determined by the r_n-values. As long as all $r_n \leq 1$, the market will just die out completely. In any other case, it is exactly the (group of) supplier(s) with the maximum r to prevail over time. In other words, if the indiviual r_n of a given supplier is not the largest one, it inevitably means the long-term exit from the market. Some sample simulations illustrating this aspect are depicted in Figure 2.

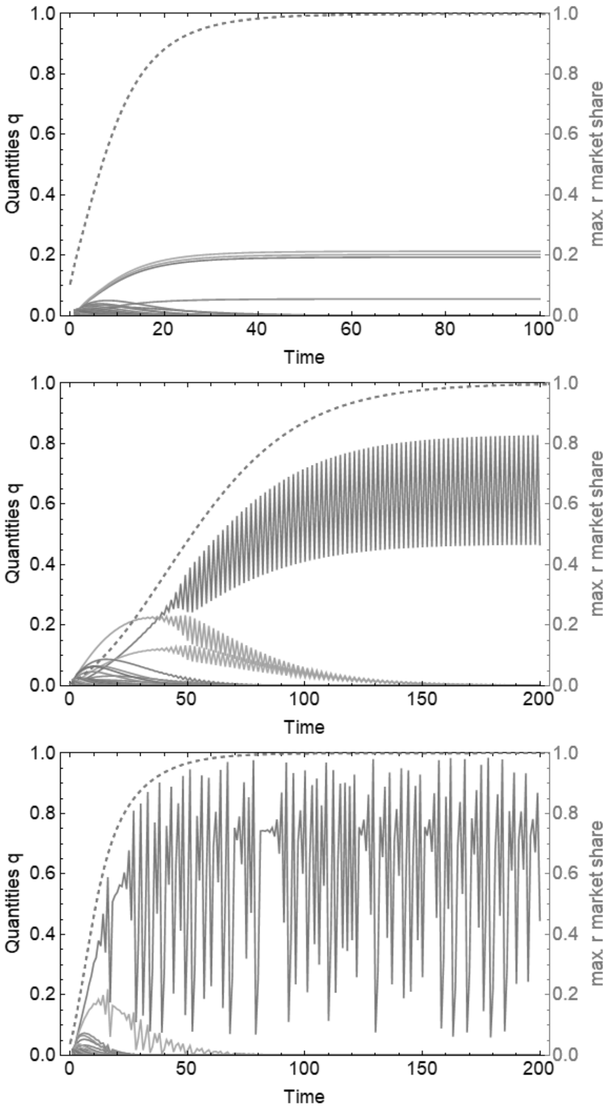

Figure 2: Dynamics in a competitive setting of 50 suppliers starting with initial quantities $\mathbf{q}_n(0)$ both random and small, as well as randomly assigned r_n. The red dashed line indicates the market share of the (group of) supplier(s) with maximum r.
(top) 4 suppliers with maximum $r = 3.0$, the market becoming stationary with $\mathbf{Q}_\infty = 2/3$.
(middle) 1 supplier with maximum $r = 3.34$, the market becoming cyclic with period 2.
(bottom) 1 supplier with maximum $r = 3.94$, the market becoming chaotic.

Long-term Market Dynamics

The model approaches a monopolistic or oligopolistic scenario in the long run. Exploiting the situation of only the supplier(s) with the (same) maximum r to be still alive and active allows to derive a simpler equation directly describing the long-term dynamics of the overall market:

$$\mathbf{Q}(t+1) = r \cdot \mathbf{Q}(t) \cdot (1 - \mathbf{Q}(t)). \qquad (3)$$

This step-wise dynamics turns out to be identical to the so-called logistic map, presumably the most prominent equation in the history of chaos, allowing for an overwhelming variety of dynamical behaviours just determined by the actual value of r [6].

As mentioned above, for $0 < r \leq 1$, no market will exist in the long run. For $1 < r \leq 3$, the system converges to a finite and stationary market of size $\mathbf{Q}_\infty = 1 - \frac{1}{r}$, as can be seen in Fig. 2, (top). For r slightly larger than 3, the potential stationary solution - in form of the fixed point mentioned above - becomes unstable, and the system shows a bifurcation leading to a dynamical pattern of period 2, cf. Fig. 2, (middle).

Generally, the interval $3 < r < 4$ contains periodic market cycles for any natural period and plenty of chaotic dynamics, as for the sample case depicted in Fig. 2, (bottom).

Analogous to [6], and for a better understanding of the overall situation, the long-term market sizes are indicated in Fig. 3 for the full range $0 < r < 4$ (top), as well as for some exemplary sub-range (bottom).

Clearly, the long-term market sizes are restricted to specific values or confined to certain bands, with rather stable islands to be located in close vicinity to chaotic regions. Thus, a small change in r can drastically affect the resulting market dynamical behaviour as typical for complex systems.

4 Further Aspects

This work shows that even simple, constant decision-making behaviours of suppliers can result in an abundance of different market dynamics. In particular, a market according to this model could even follow cycles of any period - at least in principle.

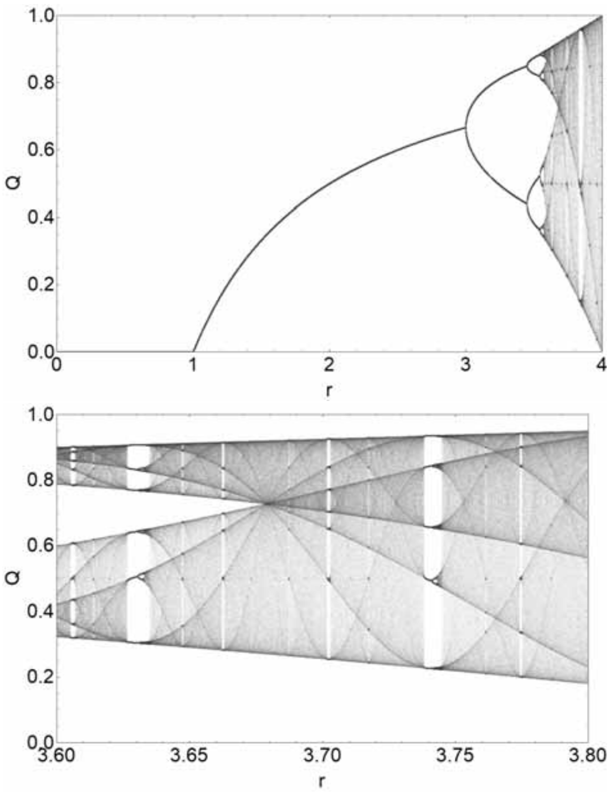

Figure 3: Long-term values for the total market size $\mathbf{Q}$ depending on r in the full relevant range **(top)** and as an exemplary zoom-in **(bottom)**, analogous to [6]. Illustrations indicate the last 100 market sizes after 10.000 time steps starting from $\mathbf{Q}(0) = 0.5$, for 20.000 different r-values along the x-axis.

This is in no contradiction to other time-related mechanisms and aspects also known to cause market cycles, such as dead times or supplier memories. Despite its simplicity and limitations, the model might help to indicate, in which markets to expect chaos - or not, cf. e.g. [7].

It should be noted, that even though this work sets the focus on total market sizes, the dynamics of the dimensionless unit price $\mathbf{P}$, normalized to P_{max}, is directly correlated via $\mathbf{P} = 1 - \mathbf{Q}$ for all times.

While a profit consideration is straightforward to achieve, e.g. [5], allowing a change of $r_n(t)$ over time is far beyond the scope of this work: On top of the inherent complexity already contained in the model for constant r_n, other layers of complexity are expected to emerge.

For example, suppliers simply adapting $\varepsilon_n(t)$ based on any strategy or investing parts of sales in cost-cutting activities in order to reduce $c_n(t)$ go along with all kinds of interactions assumed to lead to overall market patterns far from trivial.

From a supplier's perspective, there is also the immanent dilemma between the basic need for ensuring long-term existence on the market, while still somehow receiving (or even maximizing) profit.

Publication Remark

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