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On stabilizing volatile product returns

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ABSTRACT

As input flows of secondary raw materials show high volatility and tend to behave in a chaotic way, the identification of the main drivers of the dynamic behavior of returns plays a crucial role. Based on a stylized production-recycling system consisting of a set of nonlinear difference equations, we explicitly derive parameter constellations where the system will or will not converge to its equilibrium. Using a constant elasticity of substitution production function, the model is then extended to enable coverage of real world situations. Using waste paper as a reference raw material, we empirically estimate the parameters of the system. By using these regression results, we are able to show that the equilibrium solution is a Lyapunov unstable saddle point. This implies that the system is sensitive on initial conditions that will hence impede the predictability of product returns. Small variations of production input proportions could however stabilize the whole system.

1. Introduction

Recycled materials are of increasing importance in modern production economies. Thus, from an economic and ecological point of view, the integration and control of such inputs in existing production systems is of considerable importance. The management of these product returns is a central element in reverse logistics tasks which attempts to cover the cost-efficient flow of raw materials or finished goods "from a point of consumption to the point of origin" (Rogers & Tibben-Lembke, 1998). The use of secondary materials is challenging in practice, due to the fact that product return rates are highly volatile over the course of time. An example can be seen in Fig. 1, that depicts growth rates of the industrial collection of waste paper in Austria. As Norek (2002) points out, this variability of returns directly impacts production costs, and it is thus important at a "tactical level for procurement decisions, capacity planning and disposal management" (Toktay, van der Laan, & De Brito, 2004).

As a consequence, the lack of control of these inputs may make firms reluctant to expand their usage of secondary materials. Hence, the knowledge of the causes for this variability in product returns is crucial for managerial decision making. Nevertheless, as Norek (2002) points out, "returns management strategies may be the most neglected part of many supply chain practices". By focusing on the waste paper industry as a reference industry, this article explicitly addresses the question of efficient product returns management and identifies the main drivers of the dynamic behavior of waste paper returns in a stylized production-recycling system. In such a system, production in one period causes return flow of products in another period. These returns can then be used for the production of new products in the following period.

The paper/carton board industry is one of the oldest industries making use of secondary raw materials. Its usage of waste paper in order to produce new paper or carton board is thus widespread. In contrast to other waste streams, the collection systems for waste paper are well-established in many European countries, the US and Asian countries. While recycling rates are constantly increasing (see for example European Recovered Paper Council, 2013), return streams continue to show high variability. This problem was already addressed by Pearce and Grace (1976), who analyzed various policies in order to stabilize secondary raw material markets.

In order to explain these fluctuations, we distinguish between exogenous and endogenous factors. While exogenous factors come from the model's outside world, endogenous factors are inherent to the model itself. The most commonly mentioned exogenous factor for explaining waste paper quantities is the GDP. McCarthy and Lei (2010), for instance, use regression analysis to quantify the (positive) impact of a GDP increase on the available amount of waste paper. Again focusing on the waste paper industry, further factors such as the number of housing starts (Duckett, 1978), the index for industrial production (Turner & Grace, 1977), the unemployment rate (Li & Luo, 2008) or the degree of urbanization (Berglund, Söderholm, & Nielson, 2002; McCarthy & Lei, 2010) are all found to be influencing factors on the availability and/or the demand for waste paper.

Especially when the market for waste paper is analyzed from a macroeconomic point of view, it can be seen that fluctuations in

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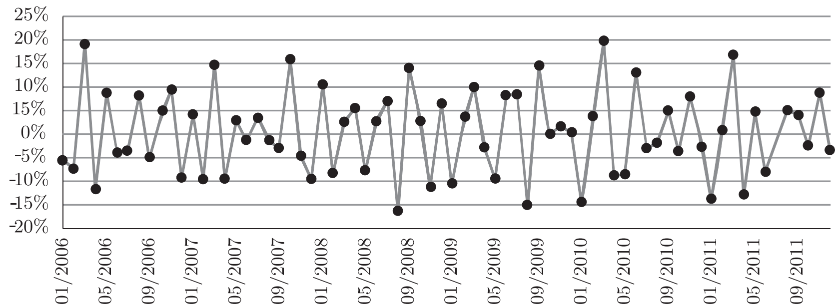

Fig. 1. Growth rates of the industrial collection of waste paper in Austria. *Source*: Altstoff Recycling Austria

the amount of available waste paper are heavily amplified by fluctuations in global trade. According to figures from the Confederation of European Paper Industries (CEPI, 2012), China represents by far the biggest demand market for European and US waste paper. This may not simply be the result of China's huge demand for raw materials, but may also be caused by China's large surplus in the balance of trade. As more products are transported from China to European or US destinations than in the opposite direction, the transportation cost from Europe/US to China are much lower than from China to Europe/US (according to trade data from EUROSTAT, data on transportation cost from CEPALSTAT and evidence from the US market for waste paper from Forstall (2002)). In addition, the accessibility and availability of collection facilities, as well as consumers' awareness of the importance of waste paper recycling, are both major factors in determining long-run collection rates and hence determining available amounts of waste paper.

The bullwhip effect, i.e. the tendency of a supply chain to develop increasingly large fluctuations of order and inventory quantities is a major source of supply chain inefficiency according to Yao and Zhu (2011). While the bullwhip effect is well-studied in forward supply chain management, there is still few literature on this in the context of closed-loop supply chains. With respect to forward supply chains, Lee, Padmanabhan, and Whang (2004) identify demand signal processing, order batching, fluctuating prices of products as well as rationing gaming to be the major sources for the occurrence of these fluctuations. Yao and Zhu (2011) then focus on the role of IT usage in dampening the bullwhip by using electronic linkages between buyers and sellers within a supply chain.

The present article focuses on the effect of variations of some structural parameters like the collection rate, production conditions or the landfilling rate on the variability of product returns. The framework for our analysis is a simplified production-recycling system, where returns are a function of past periods' production. In contrast to the existing literature on the dynamic behavior of closed-loop supply chains, which mainly relies on simulations studies, we analyze the dynamics of product returns by using a system of nonlinear difference equations. This allows us to calculate an equilibrium point of the system in closed form. Using this system of difference equations, we are able to derive conditions for the system to convergence to its equilibrium or for chaotic behavior. In particular, the Lyapunov exponents allow us to gain insights into parameter constellations, where chaotic behavior can be expected. The comparison of two different production functions (linear and CES, i.e. constant elasticity of substitution) also yields insights on how the qualitative behavior of the system is influenced by various production conditions.

The analysis of a discrete dynamical system allows for the characterization of the qualitative properties of the system in closed form. This permits rigorous sensitivity analysis that does not rely on simulation studies. The results then enable us to derive managerial implications in order to develop strategies for effective reverse logistics decision making.

The present paper is organized as follows: Section 2 gives an overview on the existing related work, while Section 3 then describes the framework of our model. The production-recycling system is modeled as a discrete nonlinear dynamical system. Section 5 analyzes the qualitative properties of the system by using the theorems from Section 4.1. Sections 5.1 and 5.2 derive and discuss the insights gained from the two models for the effective management of product returns.

2. Related work

Sustainable supply chain management (SSCM) is concerned with sustainability considerations in the forward as well as in the reverse chain (see for example Bloemhof-Ruwaard & Nunen, 2005; Gupta & Palsule-Desai, 2011), where the increase of product return quantities is considered to be a major goal of SSCM. While on the one hand, the usage of secondary materials in production processes is clearly desirable from an ecological point of view, the high variability of product returns over time also raises problems in managerial decision making. As a result, the dynamic behavior of closed-loop supply chains is attracting growing attention in both research and practice.

As chaotic behavior limits the predictability of product returns, it is crucial to know when a dynamic system may behave chaotically. The facilitating factors for chaotic behavior in supply chains were analyzed by Hwarng and Xie (2008) in a forward supply chain setup. The authors used the classical beer distribution model and quantified the system's degree of chaos by calculating Lyapunov exponents.

Another research stream explains fluctuations that occur in both forward and closed-loop supply chains by the bullwhip effect. Zhou and Disney (2006) studied the reasons for the bullwhip phenomenon within a closed-loop supply chain in continuous time using control theory. The authors found that returned products can be used to reduce inventory variance and hence dampen the bullwhip. According to the authors, a closed-loop supply chain turned out to be more cost-efficient than a conventional forward supply chain. In contrast, analyzing the beer game using system dynamics, Huang and Liu (2008) found that the system's tendency to show bullwhip like behavior is always greater in closed-loop supply chain than in a forward supply chains. This finding is also supported by Chatfield and Pritchard (2013), who conclude that supply chains with return quantities exhibit a larger bullwhip effect, using an agent-based simulation approach and seeing returns as negative order quantities. Adenso-Dìaz, Moreno, Gutiérrez, and Lozano (2012) then relativized these conflicting results by using a system dynamics approach in a similar setup as Huang and Liu (2008). They found that the bullwhip effect may be dampened or amplified by the level of the collection rate.

The literature on the value of information (see for example De Brito & van der Laan, 2009; Ketzenberg, 2009; Toyasaki, Wakolbinger, & Kettinger, 2013) also addressed the significant uncertainties