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**The impact of product returns and remanufacturing uncertainties on the  
dynamic performance of a multi-echelon closed-loop supply chain**

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**Abstract**

We investigate a three-echelon manufacturing and remanufacturing closed-loop supply chain (CLSC) constituting of a retailer, a manufacturer and a supplier. Each echelon, apart from its usual operations in the forward SC (FSC), has its own reverse logistics (RL) operations. We assume that RL information is transparent to the FSC, and the same replenishment policies are used throughout the supply chain. We focus on the impact on dynamic performance of uncertainties in the return yield, RL lead time and the product consumption lead time. Two outcomes are studied: order rate and serviceable inventory. The results suggest that higher return yield improves dynamic performance in terms of overshoot and risk of stock-out with a unit step response as input. However, when the return yield reaches a certain level, the classic bullwhip propagation normally associated with the FSC does not always hold. The longer remanufacturing and product consumption lead times result in a higher overshoot and a longer time to recover inventory, as well as more oscillation in the step response at the upstream echelons. We also study bullwhip and inventory

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