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Inventory change, capacity utilization and the semiconductor industry cycle

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ABSTRACT

This paper aims to investigate the relationship between inventory change and the industry cycle in a deeper way. The nonlinear, two-state, trivariate, Markov regime-switching model developed in this paper which includes inventory change, capacity utilization and chip sales not only obtains satisfactory out-of-sample forecasts of the probability of the industry being in recession, but also, through the regimes identified by the model, provides interesting stories of dynamics within the industry and new evidence that the change in semiconductor inventory is in fact countercyclical with respect to chip sales.

1. Introduction

Kahn (2003) addresses the role of inventory in business cycles by quoting Alan Blinder's (1986) well-known remark that "the business cycle, to a surprisingly large degree, is an inventory cycle." In the long-established theories of inventory, changes in inventory have usually been attributed to firms' actions to reduce the adjustment costs of their production or to lower the ordering costs of intermediate goods. These theories provide different predictions of aggregate production, sales and inventory. Although many studies have investigated the relationship between inventory and the business cycle, to the best of our knowledge, no effort has been made to explore how the change in inventory may affect industry cycles, despite their evident importance for the firms involved in these cycles and for their contribution to the business cycles. Therefore, this paper is designed to remedy this deficiency in the literature.

Among all of the manufacturing industries, the semiconductor industry is interesting because it generally has higher capital-to-sales as well as R&D-to-sales ratios and faster growth rates than other industries. It is estimated that a new modern semiconductor fabrication plant (or "fab") may cost US$3 billion today, as the semiconductor industry has experienced huge fluctuations, ranging from a positive 70% to a negative 40% annual growth during the past 40 years. Hence, how to precisely forecast the turning points of the semiconductor industry cycles in order to secure the enormous investment turns out to be a concern and a challenge in the industry. Besides, as indicated by industry practitioners, the semiconductor inventory which regularly counts for more than 40% of suppliers' revenue is an important gauge of industry health, and the stockpile amount at any point in time also shows the confidence of the supply chain in future prospects. Too little inventory implies concern for possible industry downturn ahead as manufacturers expect demand to plunge, while too much inventory is also a problem, raising worries of oversupply that force down average selling prices (Stiefel, 2012). Thus, the semiconductor industry seems to provide a suitable case for us to carry out this inventory–industry cycle investigation.

Despite the importance of the semiconductor industry in the study of industry cycles, very little research effort has been devoted to this area (Liu, 2005; Liu and Chyi, 2006; Tan and Mathews, 2007). Among them, Liu (2005) was the first to survey possible explanatory factors of the global semiconductor industry cycles, proposing a 12-variable unrestricted vector autoregressive (VAR) model to identify the main explanatory factors during 1994:05–2001:12.[1] He observed that both the inventory and the fab capacity play important roles in signaling the future state of the semiconductor business, i.e., both inventory level and overcapacity are closely related to the semiconductor industry cycles. Furthermore, Liu and Chyi (2006) used growth in chip sales to build a univariate Markov regime-switching model to capture the

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[1] Possible explanatory factors surveyed by Liu (2005) are summarized in Table 1.

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industry cycle. The results of their analysis indicate that the expected duration of expansion in the semiconductor industry is about eight months, while the expected duration of contraction is about four months. This finding is consistent with the observation of the business cycles in the past that the duration of an expansion is twice the duration of a business recession, although the duration of the semiconductor industry cycles are one half of the duration of the business cycles. Based on this univariate Markov regime-switching model, Liu and Chyi (2006) also obtained successful in-sample predictions of the contractions of the semiconductor industry sales during the period of 1990:01–2003:08. However, no out-of-sample forecast was carried out in their study. In contrast, Tan and Mathews (2007) investigated the semiconductor industry cycles from various perspectives for the dating and identification of cycles. They proposed a non-parametric method which, according to Harding and Pagan (2002), could be better than a parametric one judging from its simplicity, transparency, robustness and replicability. They also examined the components of the semiconductor industry cycles by performing a Fourier analysis to demonstrate the different cyclical components underlying the date series. They concluded that there are multiple sources of the cyclicality, including a one-year seasonal cycle, a four-year Kitchin inventory cycle, and an industry-specific cycle with a length of 2.3 years. However, their non-parametric analyses are unable to either identify the specific factors contributing to the industry-specific cycle or to provide any prediction of the turning points in the industry cycles.

Therefore, this paper is designed to fill the gap in the empirical literature of the inventory–industry cycle nexus in the following ways. Firstly, we investigate the relationship between inventory change and the semiconductor industry cycle in a new nonlinear analytical framework in contrast to the traditional linear-quadratic inventory model and the non-parametric analyses. A trivariate Markov regime-switching model that includes inventory change, fabrication capacity utilization representing production, and chip sales is proposed to study the dynamics within the semiconductor industry. The empirical results from our analyses suggest that the changes in semiconductor inventory are countercyclical with respect to chip sales, and imply that the production-smoothing theory is superior to the stockout-avoidance theory in some aspects in terms of explaining inventory changes in the semiconductor industry. Secondly, based on the same trivariate Markov regime-switching model, we make a special effort to provide the out-of-sample forecasts of the turning points of the semiconductor industry cycles. The results of these predictions are in fact quite satisfactory.

The remainder of this paper is organized as follows. Section 2 reviews the existing literature on the relationship between inventory and the business cycle. In Section 3, we introduce our trivariate Markov regime-switching model and data. Empirical findings regarding the industry dynamics and the out-of-sample forecasting performance from our model are given in Section 4. Section 5 concludes this paper.

2. Inventory change and the business cycle

According to Blinder and Maccini (1991), the decline in inventory is responsible for 87% of the fall in total output during the average U.S. recession after World War II. Hence, understanding inventory change is important for understanding business cycles. In a similar vein, as the inventory level counts for more than 40% of the semiconductor industry revenue, inventory change is also critical to the industry cycle. Since there is no direct theoretical model discussing the relationship between inventory change and the industry cycle, below we borrow and review theories from the macroeconomic literature on the inventory-business cycle nexus.

In the macroeconomic literature, two essential theories are often utilized to clarify the role of inventory in the business cycle. The first theory proposed by Blinder (1986) is called the production-smoothing theory, which assumes that firms hold inventories to smooth the time path of production. By doing so, they are able to lower the average costs of production under demand uncertainty when the cost function is convex. This theory predicts that inventory is countercyclical with respect to sales. The other theory of Kahn (1987) on stockout-avoidance assumes that firms keep inventories in order to prevent losses of opportunity for potential sales. When production takes time and is unable to respond to demand shock immediately, firms have an incentive to over-produce in response to unexpected demand. This results in procyclical inventory.

In the existing empirical literature, Blanchard (1983), Blinder (1986) and Ramey and West (1999) all provide evidence that inventory is procyclical in most industry-level and aggregate data. These findings are in favor of the stockout-avoidance theory. To match inventory theory with the real world, Abel (1985), Kahn (1987) and West (1986) introduced the stockout-avoidance motives into their theoretical models. Ramey (1991), on the other hand, introduced nonconvex costs of production into his model. In addition, Kahn (1992) asserted that inventory is under a nonnegative constraint.

More recently, Kahn and Thomas (2004) observed that the production-smoothing theory is more consistent with the behavior of aggregate inventories in postwar U.S. when aggregate fluctuations arise from technology shocks, rather than from preference shocks. Wen (2005) further examined the aggregate data from the U.S. and other OECD countries and concluded that inventory is strongly countercyclical at relatively high frequencies (e.g., 2–3 quarters per cycle) and is procyclical only at relatively low frequencies such as the business-cycle frequencies (e.g., 8–40 quarters per cycle). Moreover, Herrera and Pesavento (2005) used a multiple-break model to explain the decline in U.S. output volatility. They found that reductions in volatility since the mid-1980s extend not only to manufacturing inventories, but also to sales. As stated by Milgrom and Roberts (1990), the reduction in production cycles and delivery times could have resulted in lower intermediate- and finished-goods inventory levels. As for the volatility of inventories, the introduction of new technologies could have resulted in smaller and quicker adjustments to intermediate- and finished-goods inventories, with little change in raw materials.

The traditional linear-quadratic model of optimal inventory stock with unit roots which predicts cointegration between inventories and sales has been regarded as the standard model for empirical analysis of inventory change.[2] For example, Ramey and West (1999) consider the following decision problem:

$$\max_{\{Q_t,H_t\}_{t=0}^{\infty}} E_t\left\{\sum_{j=0}^{T}\beta^j\left(P_{t+j}S_{t+j}-C_{t+j}\right)\right\}, \tag{1}$$

subject to a cost function, Eq. (2), and a production function, Eq. (3);

$$C_t=\left(\frac{1}{2}\right)\left\{a_0\Delta Q_t^2+a_1Q_t^2+a_2\left(H_{t-1}-a_3S_t\right)^2\right\}+U_{ct}Q_t, \tag{2}$$

$$Q_t=S_t+H_t-H_{t-1}. \tag{3}$$

P_t is the real price (i.e., ratio of output price to the wage), S_t is the unit sales, Q_t is the quantity produced, H_t are inventories, C_t is the cost of production, U_{ct} is the shock to marginal cost of production depending on both observable and unobservable variables, β is a discount factor, $0\leq\beta<1$, and E_t is the expectations conditional of information known at period t. The explanation of cointegration between inventories and sales developed from the above model assumes that S_t has a unit root and U_{ct} is stationary. The cointegrating parameters are estimated

[2] For example, Blanchard (1983), West (1986), Eichenbaum (1989), Ramey (1991), Krane and Braun (1991), Kashyap and Wilcox (1993), Durlauf and Maccini (1995), Fuhrer et al. (1995), West and Wilcox (1994, 1996), Humphreys et al. (2001) and Albertson and Aylen (2003).