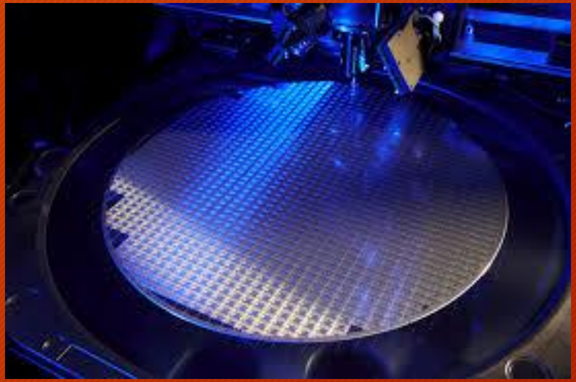


The Semiconductor Industry Cycle: Overview

Wen-Hsien Liu

Department of Economics

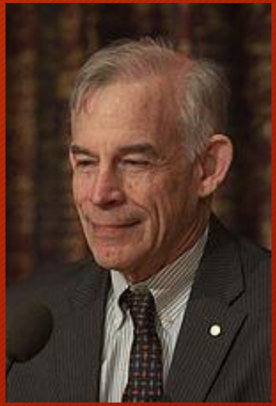
National Chung Cheng University

Background and motivation

- Some stylized facts:
  - Semiconductors has been regarded as the main engine of the IT revolutions.
  - Moore's Law: the number of transistors in a dense integrated circuit doubles approximately every two years. (1965: 12 months; 1975: 24 months; Now 18 months)
  - A highly fluctuated industry (in terms of sales growth) with abnormally high ratios of R&D spending and capital investment which might be easily (and frequently) influenced by the business cycles and some macroeconomic shocks.
- The economic growth of Taiwan has been heavily relied on the exports of semiconductors since 2000s.
- A lack of the systematic study on the causes of the semiconductor industry cycles and a comparison of the practical forecasting methods in the literature.

Research questions

1. How to build an econometric model to explain the dynamics inside the semiconductor industry and the causes of the cycles?
   - The VAR model (Sims, 1980, *Econometrica*)
   - The Markov regime-switching models (Hamilton, 1989, *Econometrica*)
   - Model uncertainty and Bayesian Model Averaging (BMA)
2. How to predict the sales and cycles more accurately?
   - Turing-point forecast
   - Bootstrap prediction interval
   - High-dimensional method (BMA vs. LASSO)



Chris Sims
(1942/10/21)

James Hamilton
(1954/11/29)

Related works

1. Liu, W.-H., 2005, “Determinants of the Semiconductor Industry Cycles,” *Journal of Policy Modeling*, 27, 853-866.
2. Liu, W.-H. and Yih-Luan Chyi, 2006, “A Markov Regime-Switching Model for the Semiconductor Industry Cycles,” *Economic Modelling*, 23, 569-578.
3. Liu, W.-H., 2007, “Forecasting the Semiconductor Industry Cycles by Bootstrap Prediction Intervals,” *Applied Economics*, 39, 1731-1742.
4. Liu, W.-H., C.-F. Chung and K.-L. Chang, 2013, “Inventory Change, Capacity Utilization and the Semiconductor Industry Cycle,” *Economic Modelling*, 31, 119-127.
5. Liu, W.-H. and S.-S. Weng, 2017, “On Predicting the Semiconductor Industry Cycle: A Bayesian Model Averaging Approach,” *Empirical Economics*, forthcoming.

Liu (2005)

Liu, W.-H., 2005, “Determinants of the Semiconductor Industry Cycles,” *Journal of Policy Modeling*, 27, 853-866.

Determinants of the cycles

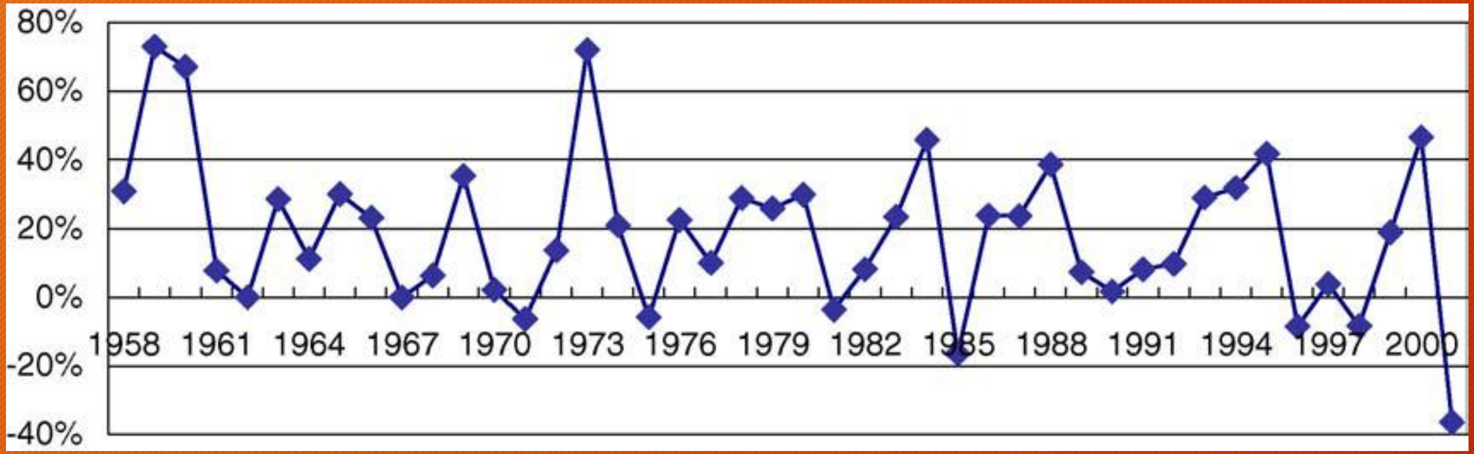


Fig. 1. Worldwide semiconductor shipments growth (1958–2001)
Source: World Semiconductor Trade Statistics (WSTS)

Allan (2001):
1965-1995: 6 cycles, i.e. 5 years per cycle

Leckie (2001a)
1970-1995:16% annual growth rate on average
1995-2000: 6% per year

Information obtained from trade journals

Table 1
Industry forecasters included in our survey of trade journals

Industry research firms (6)	Equity research firms (12)	Industry firms and associations (5)
VLSI research	J.P. Morgan	Texas Instruments (TI)
IC insight	Banc of America securities	Semiconductor industry association (SIA)
Gartner dataquest	Salomon Smith Barney	Semiconductor equipment and material international (SEMI)
Cahners In-Stat group	Morgan Stanley Dean Witter	Intel
Advanced forecasting Inc.	ABN AMRO	International SEMATECH
Infrastructure	Oppenheim Research	
	Bank Leu	
	Phillip securities	
	Prudential securities	
	Deutche Bank	
	Goldman Sachs	
	Merrill Lynch	

Table 2
Possible determinants of the semiconductor industry cycles suggested by industry practitioners

Variables	How many times mentioned?	Abbreviation in our empirical model
End markets demand/new orders	20	NO
Inventories	15	TI
Fab utilization ratio	12	UTL
Capital spending	11	–
Fab capacity	11	CAP
Global economy/macroeconomic events	9	–
Industry revenue trend	9	VS, WMB
Semiconductor equipment book-to-bill (B–B) ratio	8	–
Semiconductor sector stock index (SOX)	7	SOX
Price trend	7	PPI
Unit shipment growth	6	–
Equipment orders	4	EQO
Consumer confidence	3	CS
Exchange rate	2	–
Federal funds rate	2	FF
U.S. industrial production	2	IP
U.S. finishing-good inventories	2	–
Globalization	1	–
Semiconductor content in electronics	1	–
OECD leading indicator	1	–
Technology factor	1	–
Financial factor	1	–

The VAR(12) model and its impulse responses

Table 3
Data source

Data name	Description	Period	Source
U.S. macro-level variables			
IP	U.S. Industrial production index	1919:1–2001:12 1992 = 100	Federal reserve
FF	Federal funds rate	1954:7–2001:12	Federal reserve
CS	U.S. Consumer sentiment index	1978:1–2001:12	University of Michigan
SOX	Philadelphia semiconductor index	1994:5–2001:12	Philadelphia stock exchange
U.S. industry-level variables			
NO	New orders	1992:2–2001:12	Bureau of census
TI	Total inventories	1992:1–2001:12	Bureau of census
UTL	Capacity utilization	1967:1–2001:12	Federal reserve
EQO	North American equipment orders	1991:1–2001:12	Semiconductor equipments and materials international
CAP	Capacity	1967:1–2001:12	Federal reserve
PPI	Producer price index	1967:1–2001:12 1998:12 = 100	1998:12 = 100
SIP	Industry production index	1954:1–2001:12 1992 = 100	Federal reserve
VS	Value of shipments	1992:1–2001:12	Bureau of census
Global industry-level variable			
WMB	Worldwide market billings	1990:1–2001:12	World semiconductor trade statistics

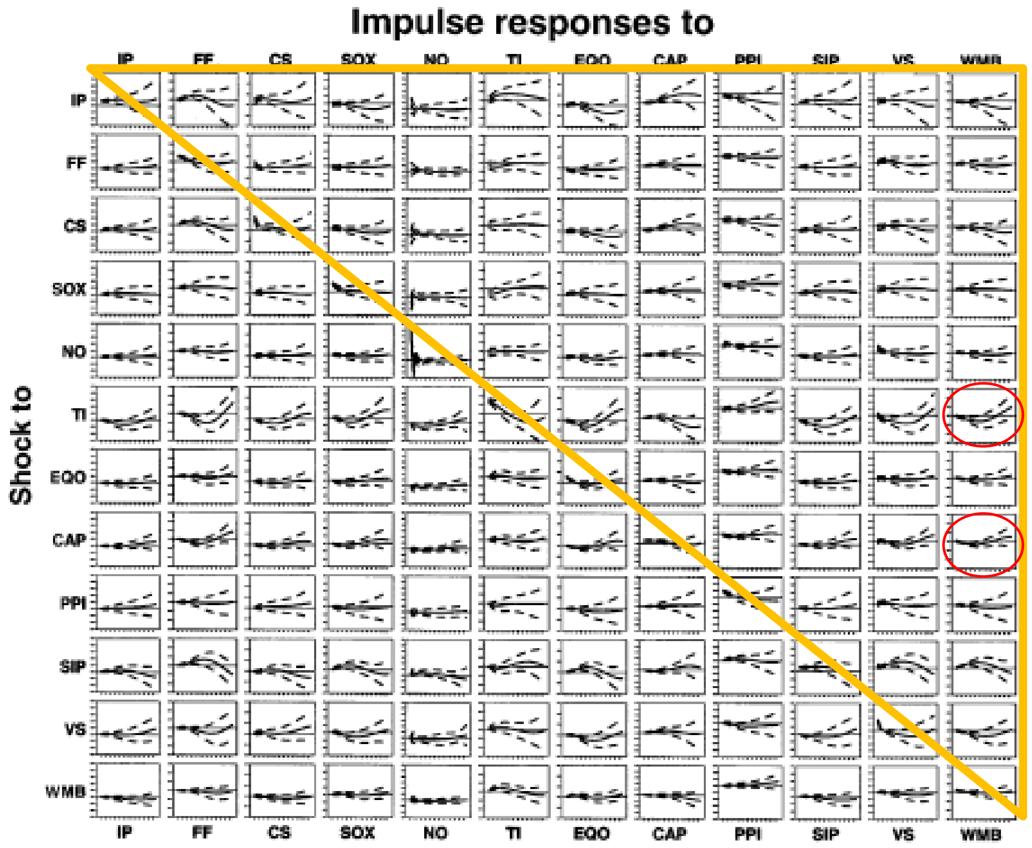


Fig. 2. Impulse responses of the VAR(12) system.

Conclusions from Liu (2005)

- Inventory (TI) and capacity (CAP) play important role in signaling the future state of the semiconductor business during 1994:5-2001:12.
- This finding is consistent with the industry practitioners' observations, such as McClean, B. (2001a). 2001 IC industry at the crossroads. *Semiconductor International*, that the semiconductor industry cycles were mainly caused by the industry overcapacity.

The Markov regime-switching model

- Univariate model (Liu and Chyi, 2006, *Economic Modelling*)
  - The simple nonlinear, two states, regime-switching model shows a successful in-sample prediction on the contraction of semiconductor industry sales during the period of 1990:01–2003:08.
- Trivariate model (Liu, Chung and Chang, 2013, *Economic Modelling*)
  - 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 during 1993:02-2001:12.
  - The change in semiconductor inventory is in fact countercyclical with respect to chip sales.

Liu and Chyi (2006)

Liu, W.-H. and Yih-Luan Chyi, 2006, "A Markov Regime-Switching Model for the Semiconductor Industry Cycles," *Economic Modelling*, 23, 569-578.

Predictions from various sources

Table 1
Predictions on when the semiconductor upturn will end

Moshe Handelsman, Advanced Forecasting	Q4 2000
Mark FitzGerald, Banc of America Securities	Q1 2001
Mehdi Hosseini, Wit Soundview	Q2 2001
Eric Wang, ABN AMRO	Q3 2001
Brett Hodess, Merrill Lynch	Q4 2001
Dan Hutcheson, VLSI Research	Q4 2001
Klaus-Dieter Rinnen, Gartner Dataquest	Q4 2002
Ron Leckie, Infrastructure	Q1 2002
Jim Handy, Gartner Dataquest	Q3 2002
Robert Castellano, The Information Network	Q3 2002
Bill McClean, IC Insights	Q4 2002

Data source: Richter (2000).

Table 2
Semiconductor market forecasts from different research firms

Sources	Issuing date	Forecasts on the industry growth rate of	
		2001	2002
Dataquest	Aug. 2001	−26%	8.3%
	Sept. 2001	−35%	3%
WSTS	May 2001	−13.5%	13.9%
	Oct. 2001	−31.6%	1%
SIA	June 2001	−13.5%	20.5%
	Nov. 2001	−31%	6%
Pathfinder	Sept. 2001	−30%	13%
IC Insights	Sept. 2001	−27%	Single-digit
	Sept. 20, 2001	−35%	recovery
VLSI Research	October 2001	−34.3%	12.7%
Financial Community	Sept. 2001	−28% to −32%	−5% to −10%

Data source: Current state of the industry, November 2001 IEF, International SEMATECH.

Probability of being in contraction

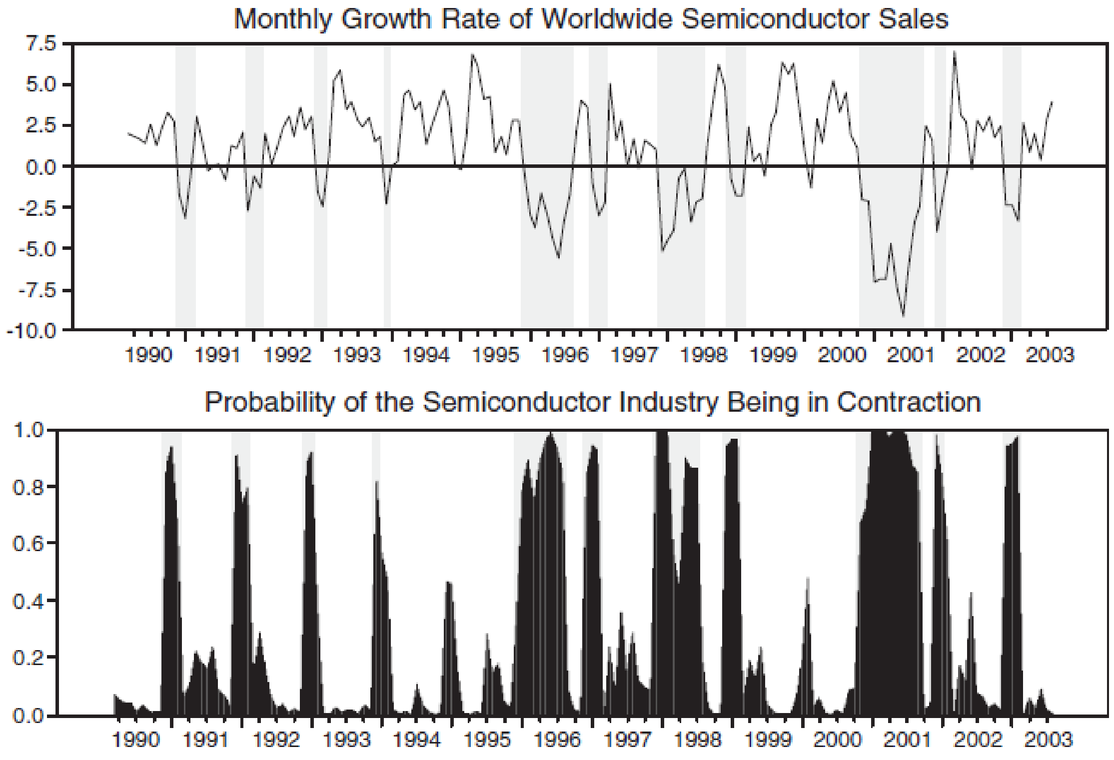


Fig. 2. Probability of the semiconductor industry being in contraction with initial $p=0.5$, $q=0.5$ and lag length$=1$.

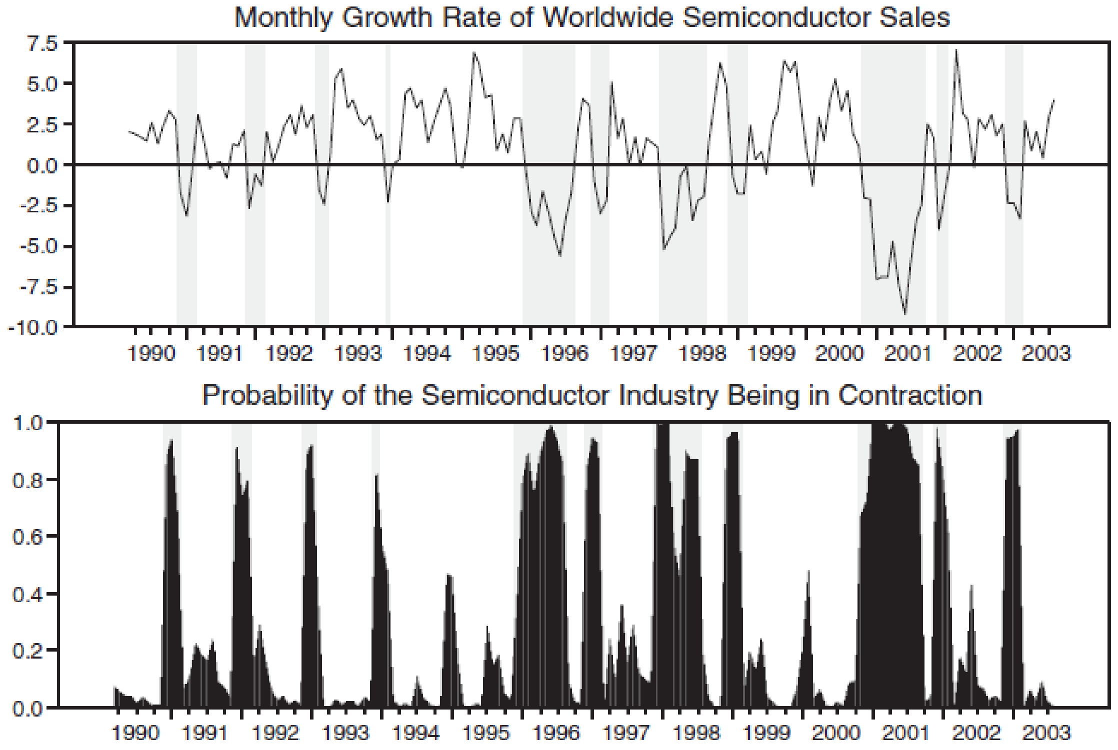


Fig. 3. Probability of the semiconductor industry being in contraction with initial $p=0.8$, $q=0.7$ and lag length$=1$.

Conclusions from Liu and Chyi (2006)

- The expected duration of expansion in the semiconductor industry is about 7.7 months, while the expected duration of contraction is about 3.7 months.
- This finding is consistent with the observation of the business cycles in past that the duration of an expansion is twice longer than the duration of a recession business, although the duration of the semiconductor industry cycles are one half of the duration of the business cycles.

Liu et al. (2013)

Liu, W.-H., C.-F. Chung and K.-L. Chang, 2013, “Inventory Change, Capacity Utilization and the Semiconductor Industry Cycle,” *Economic Modelling*, 31, 119-127.

Trends and regimes identified (vs. WMB)

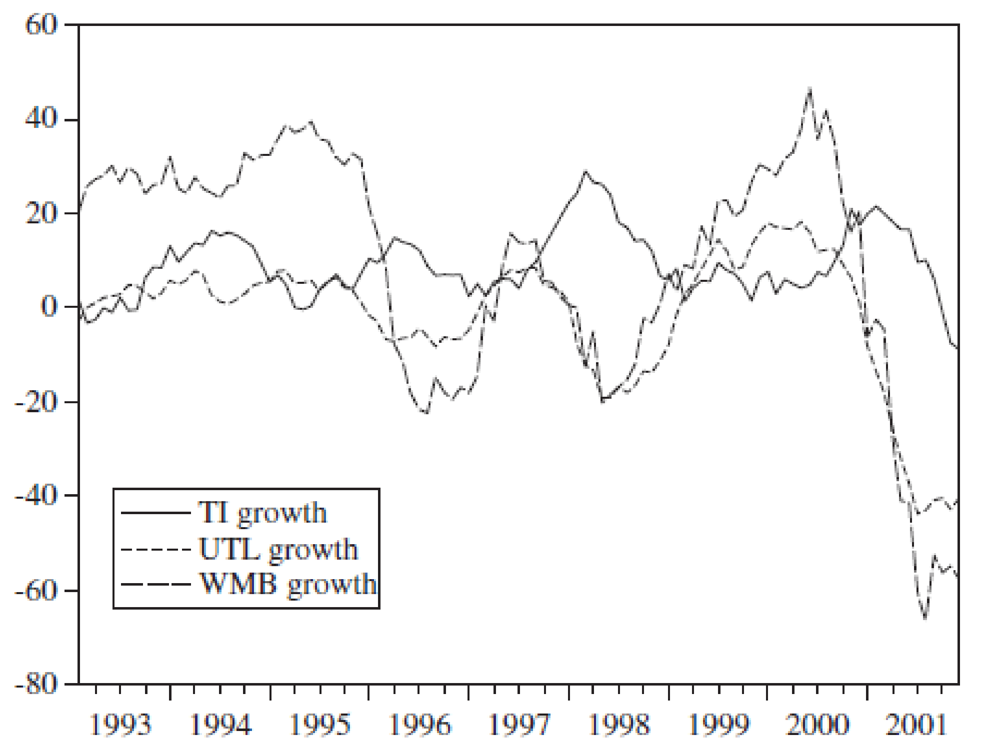


Fig. 1. Growth trends of TI, UTL and WMB (%).

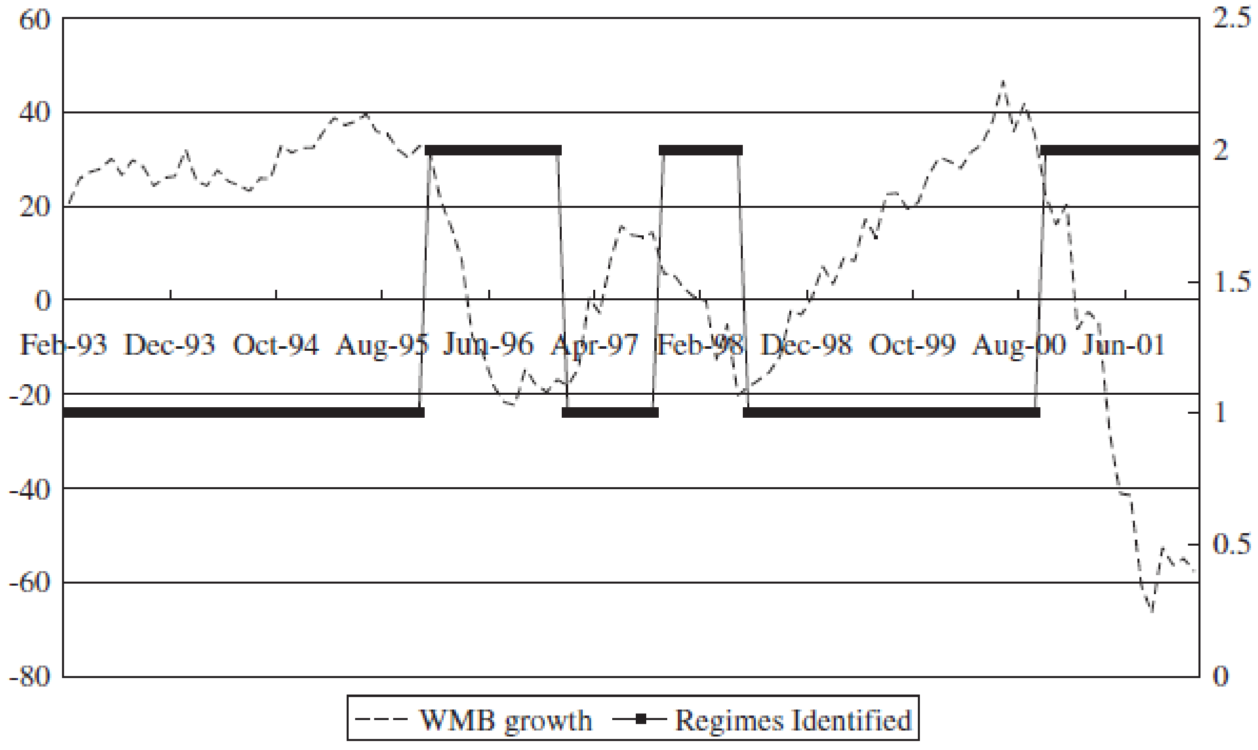


Fig. 2. Regimes identified by the model vs. chip sales growth (WMB growth) (%).

Regimes identified (vs. TI and UTL)

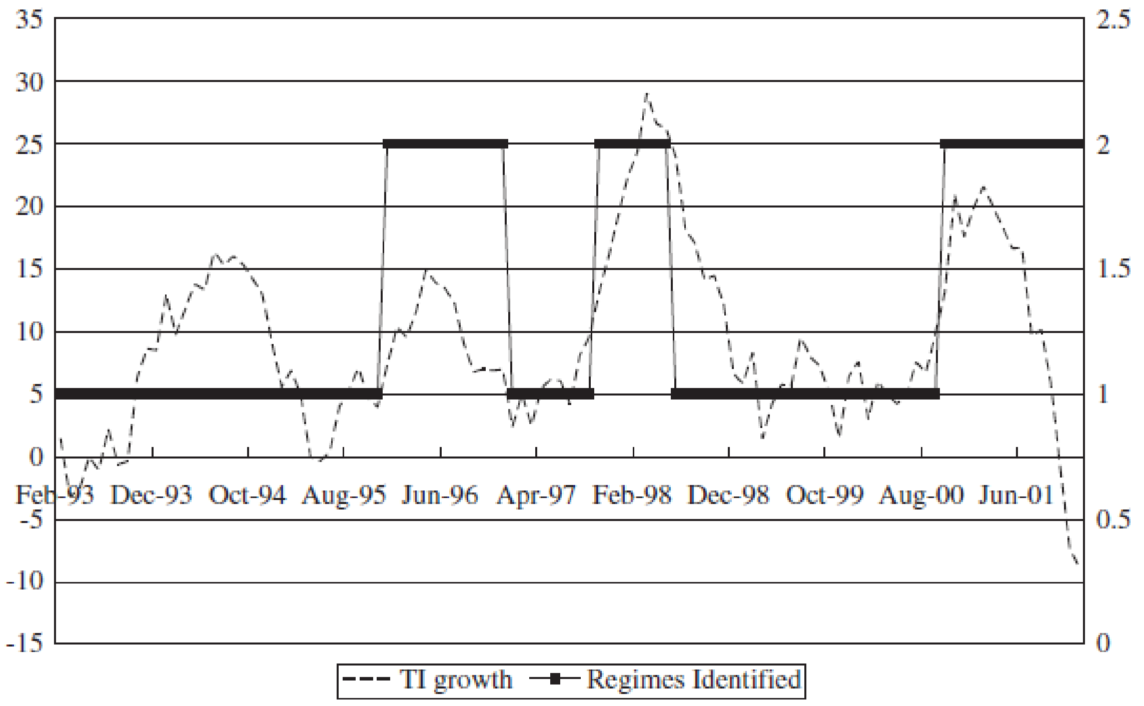


Fig. 4. Regimes identified by the model vs. inventory change (TI growth) (%).

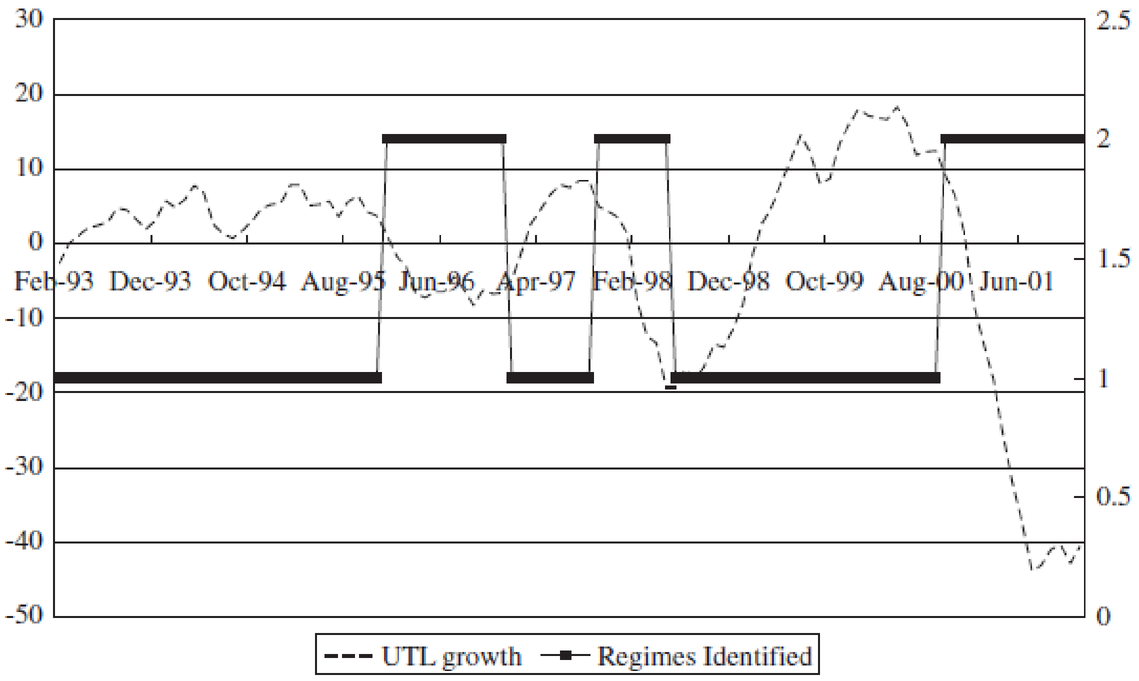


Fig. 3. Regimes identified by the model vs. utilization growth (UTL growth) (%).

Transitory probability and out-of-sample forecasting

Table 5
Estimations of transition probabilities.

Period	P_{11}	P_{21} $(=1-P_{22})$	P_{12} $(=1-P_{11})$	P_{22}
1993:02–1999:12	0.9662	0.0985	0.0338	0.9015
1993:02–2000:01	0.9667	0.0984	0.0333	0.9016
1993:02–2000:02	0.9671	0.0983	0.0329	0.9017
1993:02–2000:03	0.9676	0.0982	0.0324	0.9018
1993:02–2000:04	0.9680	0.0980	0.0320	0.9020
1993:02–2000:05	0.9685	0.0979	0.0315	0.9021
1993:02–2000:06	0.9688	0.0980	0.0312	0.9020
1993:02–2000:07	0.9692	0.0981	0.0309	0.9020
1993:02–2000:08	0.9698	0.0977	0.0303	0.9024
1993:02–2000:09	0.9701	0.0976	0.0300	0.9024
1993:02–2000:10	0.9560	0.0981	0.0440	0.9020
1993:02–2000:11	0.9534	0.0807	0.0466	0.9193
1993:02–2000:12	0.9530	0.0908	0.0470	0.9092
1993:02–2001:01	0.9535	0.0792	0.0465	0.9208
1993:02–2001:02	0.9533	0.0741	0.0467	0.9259
1993:02–2001:03	0.9531	0.0715	0.0469	0.9285
1993:02–2001:04	0.9537	0.0697	0.0464	0.9303
1993:02–2001:05	0.9546	0.0772	0.0454	0.9228
1993:02–2001:06	0.9547	0.0758	0.0454	0.9242
1993:02–2001:07	0.9550	0.0744	0.0450	0.9256
1993:02–2001:08	0.9553	0.0733	0.0447	0.9267
1993:02–2001:09	0.9552	0.0717	0.0448	0.9283
1993:02–2001:10	0.9552	0.0684	0.0448	0.9316
1993:02–2001:11	0.9555	0.0662	0.0445	0.9339

Table 6
Out-of-sample forecasting performance.

	Probability of being regime 1				Chip sales growth ($\Delta \ln WMB$)	
	Smoothed probability	Regime identified	Prediction probability	Regime identified	True value	Prediction
2000:01	0.9993	1	1	1	29.473	31.204
2000:02	1	1	0.9995	1	28.059	32.006
2000:03	0.9996	1	1	1	31.584	30.531
2000:04	1	1	0.9958	1	33.112	31.499
2000:05	0.9999	1	1	1	38.041	33.736
2000:06	0.9878	1	1	1	46.575	37.511
2000:07	0.9853	1	0.9970	1	35.854	43.152
2000:08	0.9960	1	0.9893	1	41.897	38.575
2000:09	0.7095	1	1	1	35.086	39.124
2000:10	0.0010	2	0.9912	1	22.283	37.641
2000:11	0.0014	2	0.0029	2	16.062	19.956
2000:12	0.0061	2	0.0003	2	20.388	10.016
2001:01	0	2	0.2944	2	−6.175	13.280
2001:02	0.0021	2	0	2	−2.497	−1.507
2001:03	0.0058	2	0.0002	2	−4.692	−11.420
2001:04	0	2	0.0367	2	−27.713	−9.946
2001:05	0	2	0	2	−41.055	−23.427
2001:06	0	2	0	2	−41.461	−41.927
2001:07	0	2	0.0003	2	−60.683	−47.368
2001:08	0	2	0	2	−66.476	−58.662
2001:09	0.0018	2	0.0001	2	−52.590	−66.467
2001:10	0.0009	2	0.0336	2	−56.351	−57.827
2001:11	0	2	0.0195	2	−54.856	−54.922
2001:12	0.0091	2	0.0001	2	−57.665	−56.909

Note: Regime 1 is identified if the smoothed probability is above 50% (0.50).

Conclusions from Liu et al. (2013)

- Inventory change in the semiconductor industry is in fact countercyclical with respect to chip sales. This finding is in close agreement with the predictions of Kahn (2003), Kahn and Thomas (2004) and Wen (2005) and with the alternative strategy adopted by firms during different states of the industry cycles.
- The production-smoothing theory is superior to the stockout-avoidance theory in terms of explaining semiconductor inventory change.
- Moreover, a special effort has been devoted to obtaining a satisfactory out-of-sample prediction of the turning points in the industry cycles.

Liu (2007)

Liu, W.-H., 2007, "Forecasting the Semiconductor Industry Cycles by Bootstrap Prediction Intervals," *Applied Economics*, 39, 1731-1742.

Model setups

Table 2. Data sources of the variables in the VAR system

Variable	Description	Coverage	Source
Macroeconomic variables			
IP	US Industrial production index	1919:1–2005:8	Federal Reserve
FF	Federal funds rate	1954:7–2005:8	Federal Reserve
CS	US consumer sentiment index	1978:1–2005:8	University of Michigan
NDQ	NASDAQ composite index	1971:1–2005:8	NASDAQ Stock Market
SOX	Philadelphia semiconductor index	1994:5–2005:8	Philadelphia Stock Exchange
Industry-level variables			
NO	US new semiconductor orders	1992:2–2001:12	Bureau of Census
TI	US total semiconductor inventories	1992:1–2001:12	Bureau of Census
UTL	US semiconductor capacity utilization	1967:1–2005:8	Federal Reserve
EQO	North American equipment orders	1991:1–2005:8	SEMI
PPI	US semiconductor producer price index	1967:1–2005:8	Bureau of Labour and Statistics
SIP	US semiconductor industrial production index	1954:1–2005:8	Federal Reserve
VS	US value of semiconductor shipments	1992:1–2005:8	Bureau of Census
WMB	Worldwide semiconductor market billings	1978:1–2005:8	SIA

Table 7. Comparisons of the four VAR models

				Variables											
Model	Data period	# of observations	# of variables	DIP	DFF	DCS	DSOX	DNDQ	DNO	DTI	DUTL	DEQO	DPPI	DVS	DWMB
1	1994:5–2001:12	92	11	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
2	1994:5–2001:12	92	4			✓			✓					✓	✓
3	1978:1–2001:12	288	7	✓	✓	✓		✓			✓		✓		✓
4	1978:1–2001:12	288	4	✓				✓					✓		✓

Lag = 1, 2

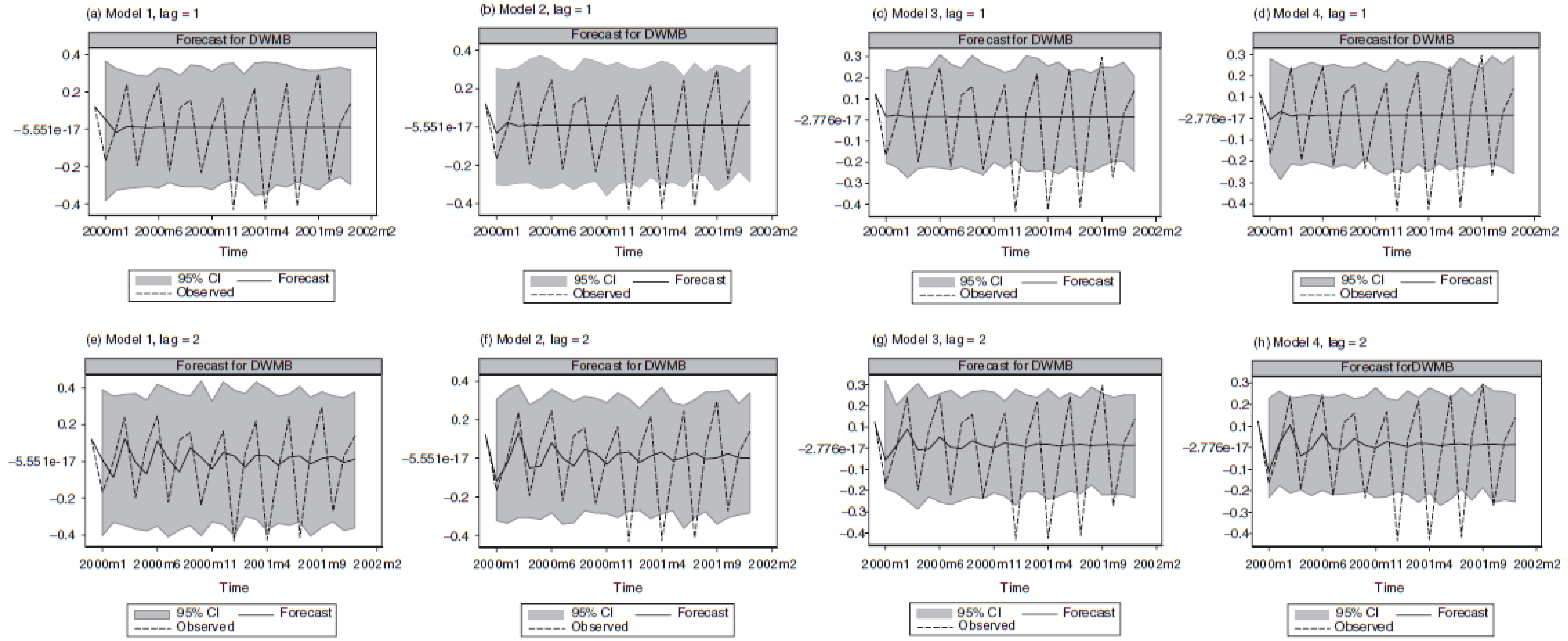


Fig. 3. Bootstrap prediction intervals of DWMB

Lag = 3, 4

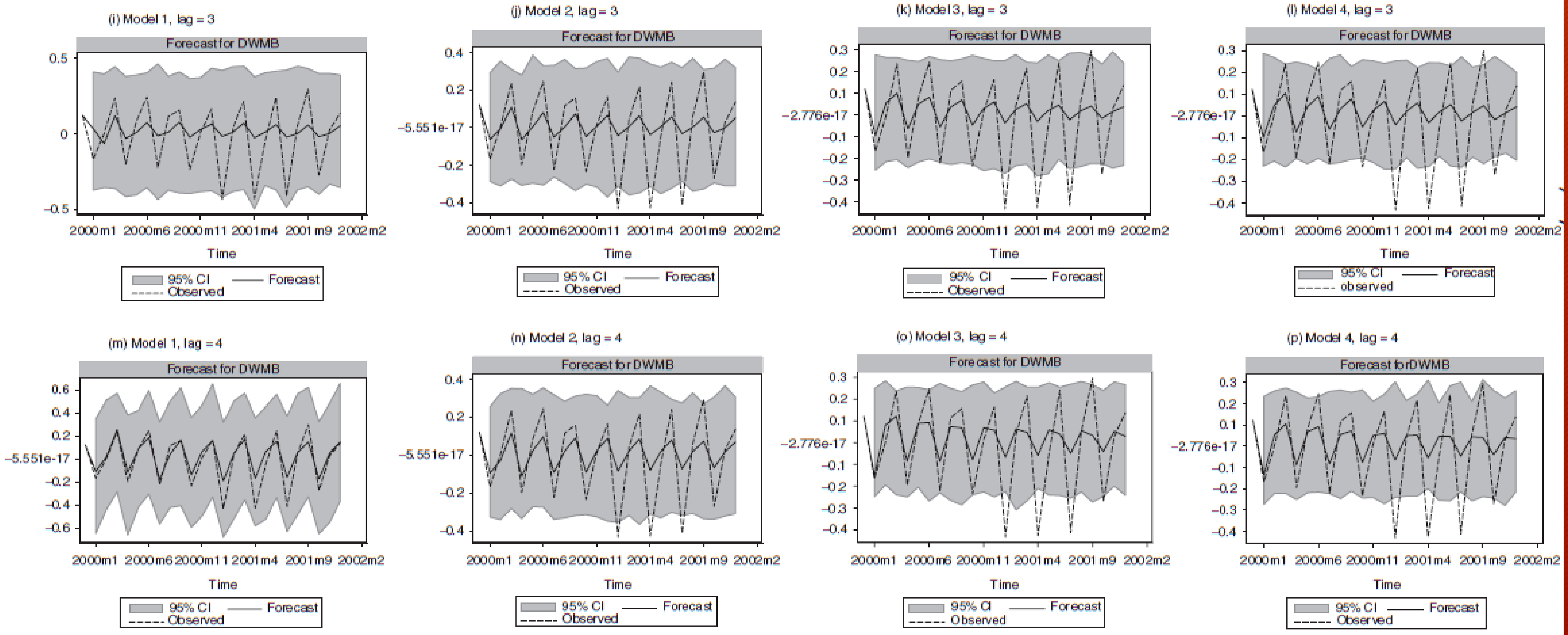


Fig. 3. Continued

Conclusions from Liu (2007)

- In addition to constructing a VAR model to conduct the out-of-sample point forecasts, this article also applies bootstrap prediction intervals on forecasting the semiconductor industry cycles.
- The carefully constructed 11-variable VAR model with appropriate lag length (not optimal lag length) can capture the cyclical behaviour of the industry and outperforms other VAR models in terms of both point forecast and prediction interval.
- The comparison of forecast performances from different VAR models also suggests that the selection of variables into the model is more important than the length of observation period, the number of variables in the model and the implementation of optimal lag length.

Liu and Weng (2017)

Liu, W.-H. and S.-S. Weng, 2017, "On Predicting the Semiconductor Industry Cycle: A Bayesian Model Averaging Approach," *Empirical Economics*, forthcoming.

Model Uncertainty

In practice, previous studies (Liu 2005, 2007; Liu and Chyi 2006; Chow and Choy 2006; Tan and Mathews 2010a, b; Liu et al. 2013; Aubry and Renou-Maissant 2013, 2014) relied heavily on the rules of thumb and subjectively selected their predictors ignoring the potential risk of the model uncertainty.

Although various econometric methods have been proposed in these studies to identify principle determinants of the industry cycles and improve the predictive accuracy, the essential question remains unsolved: When many potential explanatory variables exist, how do we know which variables should be included in the model and how important are they?

Table 1 Variable descriptions

	Series	Description	Data coverage	Source	Mean	SD
	WMB	Semiconductor world market billings	1976:3–2012:10	SIA	$17,436 \times 10^6$	5092×10^6
	Macroeconomic variables					
1	FF	Federal funds rate	1954:7–2012:11	FR	2.89%	2.24%
2	CLI	Composite leading index	1955:1–2012:10	OECD	99.87	1.52
3	IP	US Industrial production index	1919:1–2012:11	FR	91.41 (y2007=100)	5.25
4	CS	Consumer sentiment index	1978:1–2012:11	UM	86.97 (y1966=100)	14.82
	Financial variables					
5	SOX	Philadelphia semiconductor index	1994:5–2012:11	YF	435.57	174
6	NDQ	NASDAQ composite index	1993:3–2012:11	YF	2238.68	634.89
7	DJ	Dow Jones industrial average index	1896:5–2012.11	YF	10,402.19	1652.16
	Semiconductor variables					
8	CAP	Capacity	1971:1–2012:11	FR	90.64 (y2007=100)	63.3
9	SIP	Industrial production index	1972:1–2012:11	FR	69.09 (y2007=100)	47.27
10	UTL	Capacity utilization ratio	1972:1–2012:11	FR	77.65%	8.56%
11	ISR	Inventory to shipment ratio (computer and electronic products)	1992:1–2012:10	CB	1.47%	0.12
12	NO	New orders (computer and electronic products)	1992:2–2012:10	CB	$26,752.71 \times 10^6$	4429.94×10^6
13	FGI	Finished goods inventory (computer and electronic products)	1992:1–2012:10	CB	$11,380.89 \times 10^6$	1857.29×10^6
14	MSI	Materials and supplies inventory (computer and electronic products)	1992:1–2012:10	CB	$17,977.04 \times 10^6$	2971.29×10^6
15	VS	Value of shipments (computer and electronic products)	1992:1–2012:10	CB	$32,592.51 \times 10^6$	4516.29×10^6
16	TI	Total inventories (computer and electronic products)	1992:1–2012:10	CB	$47,886.77 \times 10^6$	6485.38×10^6
17	BB	book-to-bill ratio for semiconductor manufacturing equipment	1992:1–2012:10	SEMI	0.96	0.19
18	Book	bookings for semiconductor manufacturing equipment	1992:1–2012:10	SEMI	1247.71×10^6	528.23×10^6
19	Bill	Billings for semiconductor manufacturing equipment	1991:1–2012:10	SEMI	1281.27×10^6	416.04×10^6

Dependent variable:
- G_t = $dlnWMB_t$ = $lnWMB_t - lnWMB_{t-12}$

Sample period: monthly
- 1994:05-2012:10

→ 1995:05-2012:10

Potential predictors: 70
- Macroeconomic: 4
- Financial: 3
- Semiconductor: 16
- PPI: 3
- Industrial production: 7
- New order: 7
- Total inventory: 15
- Value of shipment: 15

Table 1 Variable descriptions (con't)

	Series	Description	Data coverage	Source	Mean	SD
20	PPI	Producer price index (electronic components and accessories)	1965:12–2012:11	BLS	87.02 (y1982=100)	10.54×10^6
21	ES	Retail sales for electronics and appliance stores	1992:1–2012:10	CB	7637.04×10^6	1063.36×10^6
22	ESA	Wholesale sales for electrical and electronic goods	1992:1–2012:10	CB	$23,579.75 \times 10^6$	5125.87×10^6
23	EIN	Wholesale inventories for electrical and electronic goods	1992:1–2012:10	CB	$31,468.99 \times 10^6$	5906.87×10^6
	Producer price index					
24	PPI1	Integrated microcircuits (including microprocessors and MOS memories)	1975:12–2012:11	BLS	67.68 (y1998=100)	25.9
25	PPI2	Microprocessors (including microcontrollers)	1981:6-2012:11	BLS	7983.98 (y2007=100)	21,306.72
26	PPI3	Other semiconductor devices (parts such as chips, wafers, and heat sinks)	1976:4-2012:11	BLS	77.57 (y1981=100)	12.01
	Industrial production index					
27	IP1	Computer and electronic product	1972:1–2012:11	FR	73.34 (y2007=100)	28.48
28	IP2	Computer and peripheral equipment	1972:1–2012:11	FR	68.15 (y2007=100)	25.14
29	IP3	Communications equipment	1972:1–2012:11	FR	83.37 (y2007=100)	15.13
30	IP4	Audio and video equipment	1972:1–2012:11	FR	89.56 (y2007=100)	31.38
31	IP6	Electrical equipment, appliance, and component	1972:1–2012:11	FR	95.36 (y2007=100)	10.62
32	IP7	Battery	1972:1–2012:11	FR	99.9 (y2007=100)	11.68
33	IP8	Communication and energy wire and cable	1972:1–2012:11	FR	119.78 (y2007=100)	36.26
	New orders					
34	NO2	Computer storage device manufacturing	1992:2–2012:10	CB	2530.82×10^6	1163.61×10^6
35	NO7	Other electronic component manufacturing	1992:2–2012:10	CB	4284.5×10^6	996.34×10^6
36	NO9	Household appliance manufacturing	1992:2–2012:10	CB	1814.5×10^6	212.8×10^6
37	NO11	Computers and related products	1992:2–2012:10	CB	6064.59×10^6	2244.43×10^6
38	NO12	Communication equipment	1992:2–2012:10	CB	5768.2×10^6	2168.7×10^6

Two-step data transformation:

1. Take a natural log for a positive series to linearize the relationship.
2. Take the unit root tests to verify whether the series is stationary.
   - I(1) → I(0)

Table 1 Variable descriptions (con't)

	Series	Description	Data coverage	Source	Mean	SD
39	NO14	Electrical equipment manufacturing	1992:2–2012:10	CB	2999.32×10^6	373.11×10^6
40	NO15	Search and navigation equipment	1992:2–2012:10	CB	1019.44×10^6	339.23×10^6
	Total Inventories					
41	TI1	Farm machinery and equipment manufacturing	1992:2–2012:10	CB	2465.95×10^6	491.74×10^6
42	TI2	Construction machinery manufacturing	1992:2–2012:10	CB	4101.25×10^6	820.96×10^6
43	TI3	Computer storage device manufacturing	1992:2–2012:10	CB	1380.15×10^6	305.23×10^6
44	TI4	Other computer peripheral equipment manufacturing	1992:2–2012:10	CB	2249.15×10^6	694.46×10^6
45	TI5	Communications equipment manufacturing (nondefense)	1992:2–2012:10	CB	9369.28×10^6	2814.6×10^6
46	TI6	Audio and video equipment	1992:2–2012:10	CB	849.84×10^6	160.01×10^6
47	TI7	Other electronic component manufacturing	1992:2–2012:10	CB	7507.25×10^6	1471.73×10^6
48	TI8	Electrical equipment, appliances, and components	1992:2–2012:10	CB	$13,988.66 \times 10^6$	1181.48×10^6
49	TI9	Household appliance manufacturing	1992:2–2012:10	CB	2028.38×10^6	242.68×10^6
50	TI10	Battery manufacturing	1992:2–2012:10	CB	809.49×10^6	190.11×10^6
51	TI11	Computers and related products	1992:2–2012:10	CB	6064.2×10^6	2236.67×10^6
52	TI12	Communication equipment	1992:2–2012:10	CB	$10,571.29 \times 10^6$	2533.09×10^6
53	TI13	Information technology industries	1992:2–2012:10	CB	$40,888.79 \times 10^6$	5067.3×10^6
54	TI14	Electrical equipment manufacturing	1992:2–2012:10	CB	4467.3×10^6	402.21×10^6
55	TI15	Search and navigation equipment	1992:2–2012:10	CB	2741.27×10^6	366.84×10^6
	Value of shipments					
56	VS1	Farm machinery and equipment manufacturing	1992:2–2012:10	CB	1614.76×10^6	453.99×10^6
57	VS2	Construction machinery manufacturing	1992:2–2012:10	CB	2438.65×10^6	841.25×10^6
58	VS3	Computer storage device manufacturing	1992:2–2012:10	CB	872.54×10^6	333.03×10^6

Table 1 Variable descriptions (con't)

	Series	Description	Data coverage	Source	Mean	SD
59	VS4	Other computer peripheral equipment manufacturing	1992:2–2012:10	CB	1434.87×10^6	553.99×10^6
60	VS5	Communications equipment manufacturing (nondefense)	1992:2–2012:10	CB	5319.64×10^6	2018.04×10^6
61	VS6	Audio and video equipment	1992.2–2012.10	CB	607.83×10^6	227.91×10^6
62	VS7	Other electronic component manufacturing	1992.2–2012.10	CB	4265.37×10^6	851×10^6
63	VS8	Electrical equipment, appliances, and components	1992.2–2012.10	CB	9561.81×10^6	775.86×10^6
64	VS9	Household appliance manufacturing	1992:2–2012:10	CB	1814.25×10^6	186.46×10^6
65	VS10	Battery manufacturing	1992:2–2012:10	CB	670.43×10^6	155.11×10^6
66	VS11	Computers and related products	1992:2–2012:10	CB	6109.91×10^6	2237.11×10^6
67	VS12	Communication equipment	1992:2–2012:10	CB	5714.07×10^6	1945.18×10^6
68	VS13	Information technology industries	1992:2–2012:10	CB	$26,080.83 \times 10^6$	3688.69×10^6
69	VS14	Electrical equipment manufacturing	1992:2–2012:10	CB	2986.84×10^6	299.13×10^6
70	VS15	Search and navigation equipment	1992:2–2012:10	CB	974.51×10^6	177.59×10^6

BLS Bureau of labor statistics; *CB* bureau of census; *FR* federal reserve; *OECD* Organization for Economic Co-operation and Development; *SEMI* Semiconductor Equipment and Materials International; *SIA* Semiconductor Industry Association; *UM* University of Michigan; *YF* Yahoo! Finance

Estimation Procedure of BMA

- *h*-step-ahead real time forecast: At time *t*, only data at *t-1* is available.
    - h = 0 moment-term
    - h = 3, 6 short-term
    - h = 9, 12 medium-term
    - h = 18, 24 long-term
- Uniform model prior of Fernandez et al. (2001a)
    - $g = 1/\max(T, k^2) = 1/\max(209-h, 70^2) = 70^{-2}$
- Results are based on a run with 5 million recorded drawings with a burn-in of 1 million drawings to ensure the posterior model probabilities (PMP) are properly estimated.
- 0-step-ahead:
    - Reverse-jump sampler: 381,644 different models are visited (3.2×10^{-14}% of the entire model space)
    - Average model size = 24.1564
    - The correlation between the posterior model probabilities based on the empirical frequencies of visit in the Markov chain and the exact marginal likelihood for the 10,000 best models = 0.9873.
    - It takes 13.79714 minutes on a NB with Intel core i5-3210M CPU @2.5GHZ.

Table 2 Estimates of BMA (0-step-ahead)

	(1) PIP	(2) PM	(3) PSD	(4) CPS		(1) PIP	(2) PM	(3) PSD	(4) CPS
FF	0.455	0.014	0.018	1.000	NO9	0.016	0.000	0.005	0.751
CLI	0.206	0.300	0.685	0.991	NO11	0.081	−0.006	0.023	0.014
IP	0.213	0.060	0.305	0.714	NO12	0.022	0.000	0.003	0.790
CS	**0.966**	0.177	0.056	1.000	NO14	0.078	0.004	0.016	1.000
SOX	**0.984**	0.086	0.022	1.000	NO15	0.017	0.000	0.001	0.856
NDQ	0.060	0.004	0.019	0.902	TI1	0.084	−0.010	0.038	0.041
DJ	0.169	0.020	0.050	0.986	TI2	0.028	−0.002	0.021	0.237
CAP	0.668	0.037	0.539	0.440	**TI3**	**1.000**	−0.387	0.058	0.000
SIP	0.708	0.638	0.552	0.998	TI4	0.309	−0.047	0.077	0.001
UTL	0.628	0.424	0.530	0.991	TI5	0.285	0.058	0.118	0.971
ISR	0.746	−0.885	0.853	0.003	**TI6**	**0.988**	0.168	0.050	1.000
NO	0.034	0.002	0.016	0.772	TI7	0.657	0.240	0.227	1.000
FGI	0.560	−0.116	0.117	0.000	TI8	0.269	−0.246	0.451	0.032
MSI	0.646	0.000	0.000	1.000	TI9	0.447	0.157	0.203	0.998
VS	0.590	−0.339	0.983	0.441	**TI10**	**0.954**	0.231	0.076	1.000
TI	0.126	−0.140	0.536	0.165	**TI11**	**1.000**	0.781	0.077	1.000
BB	0.022	0.000	0.005	0.924	TI12	0.317	0.087	0.154	0.986
BOOK	0.034	0.001	0.005	0.877	TI13	0.253	0.400	0.770	0.964
BILL	0.087	0.003	0.012	0.976	TI14	0.631	−0.207	0.178	0.000
PPI	0.436	0.402	0.496	0.998	TI15	0.060	0.008	0.039	0.906
ES	0.039	0.006	0.041	0.839	VS1	0.297	−0.020	0.034	0.002
ESA	0.245	0.064	0.126	0.997	VS2	0.096	−0.007	0.026	0.004
EIN	0.053	−0.009	0.052	0.121	**VS3**	**0.995**	−0.096	0.024	0.000
PPI1	0.504	0.200	0.215	0.999	VS4	0.023	0.000	0.005	0.571
PPI2	0.043	0.000	0.002	0.188	VS5	0.024	0.000	0.012	0.382
PPI3	0.059	−0.018	0.095	0.096	VS6	0.020	0.000	0.004	0.556
IP1	0.632	−0.457	0.418	0.000	VS7	0.061	−0.006	0.027	0.027
IP2	**0.971**	−0.258	0.082	0.000	**VS8**	**0.995**	0.639	0.133	1.000
IP3	0.083	−0.002	0.039	0.298	VS9	0.034	−0.003	0.021	0.053
IP4	0.033	0.001	0.006	0.838	**VS10**	**0.954**	−0.145	0.050	0.000
IP6	0.265	−0.155	0.290	0.007	VS11	0.058	−0.005	0.027	0.090
IP7	0.294	−0.047	0.080	0.001	VS12	0.030	−0.001	0.015	0.190
IP8	0.853	−0.256	0.131	0.000	VS13	0.519	−0.258	0.279	0.000
NO2	0.033	0.000	0.002	0.022	VS14	0.024	0.002	0.022	0.850
NO7	0.035	−0.001	0.009	0.149	VS15	0.050	−0.003	0.015	0.035

PIP: posterior inclusion probability
PM: posterior mean
PSD: posterior standard deviation
CPS: conditional positive sign
e.g.

SOX:

PIP = 0.984
PM = 0.086
PSD = 0.022
CPS = 100%

NO9:

PIP = 0.016
CPS = 75.1%

The prior probability of inclusion is 50% under the uniform model prior.

- > 50% effective variable (23 of 70)
- > 90% main determinants (10 of 23)

Table 3 Models with 10 highest PMP

Model	PMP	IP	CS	SOX	CAP	SIP	UTL	ISR	FGI	VS	TI	PPI1	IP1	IP2
1	0.0082	O	O	O	O	X	O	O	X	O	X	O	O	O
2	0.0079	O	O	O	X	O	O	O	X	O	X	O	O	O
3	0.0067	O	O	O	O	O	X	O	X	O	X	O	O	O
4	0.0033	O	O	O	O	O	X	O	O	O	X	O	O	O
5	0.0030	O	O	O	X	O	O	O	O	O	X	O	O	O
6	0.0025	O	O	O	O	X	O	O	O	O	X	O	O	O
7	0.0015	O	O	O	O	X	O	O	X	X	O	O	O	O
8	0.0013	O	O	O	X	O	O	O	X	X	O	O	O	O
9	0.0012	O	O	O	X	O	O	O	X	O	X	O	O	O
10	0.0012	O	O	O	O	O	X	O	X	O	X	O	O	O

Model	PMP	IP7	IP8	TI3	TI6	TI7	TI8	TI9	TI10	TI11	TI13	VS1	VS3	VS8	VS10
1	0.0082	X	O	O	O	O	O	O	O	O	O	O	O	O	O
2	0.0079	X	O	O	O	O	O	O	O	O	O	O	O	O	O
3	0.0067	X	O	O	O	O	O	O	O	O	O	O	O	O	O
4	0.0033	X	O	O	O	O	O	O	O	O	O	O	O	O	O
5	0.0030	X	O	O	O	O	O	O	O	O	O	O	O	O	O
6	0.0025	X	O	O	O	O	O	O	O	O	O	O	O	O	O
7	0.0015	X	O	O	O	O	O	O	O	O	O	O	O	O	O
8	0.0013	X	O	O	O	O	O	O	O	O	O	O	O	O	O
9	0.0012	O	O	O	O	O	O	O	O	O	O	O	O	O	O
10	0.0012	O	O	O	O	O	O	O	O	O	O	O	O	O	O

◆ The best model:
- 23 predictors
- Posterior model probability (PMP) = 0.82%

◆ Top 10 models:
- 23-27 predictors
- 3.7% of PMP
- 19 predictors are in common
  - 10 main determinants
  - 3 effective variables

◆ Binomial and beta-binomial model priors are also used for robustness check.

Table 4 PIP over various prediction horizons

$h =$	0	3	6	9	12	18	24	$h=$	0	3	6	9	12	18	24
FF	0.455	0.035	0.306	0.098	0.812	0.660	0.028	NO9	0.016	0.029	0.017	0.094	0.022	0.029	0.017
CLI	0.206	**0.932**	0.160	0.150	**0.970**	0.338	0.039	NO11	0.081	0.025	0.057	0.043	0.019	0.058	0.026
IP	0.213	**0.997**	**0.974**	0.311	0.038	0.080	0.247	NO12	0.022	0.016	0.018	0.045	0.016	0.151	0.024
CS	**0.966**	0.081	0.123	0.024	0.030	0.747	0.242	NO14	0.078	0.027	0.030	0.238	0.017	0.057	0.041
SOX	**0.984**	**1.000**	**1.000**	**1.000**	0.210	**1.000**	**1.000**	NO15	0.017	0.023	0.024	0.017	0.019	0.027	0.165
NDQ	0.060	0.064	0.080	0.025	0.034	**0.984**	0.853	TI1	0.084	**1.000**	**0.999**	**0.996**	**0.999**	0.190	**1.000**
DJ	0.169	0.092	**0.908**	0.804	0.038	0.328	0.062	TI2	0.028	**0.914**	0.105	0.755	**0.998**	**1.000**	0.039
CAP	0.668	0.101	0.564	0.197	0.176	**1.000**	**0.959**	TI3	**1.000**	**0.996**	0.110	**0.999**	**0.999**	0.037	**1.000**
SIP	0.708	0.068	0.634	0.296	0.714	**1.000**	0.590	TI4	0.309	0.026	0.079	0.023	0.390	0.254	0.057
UTL	0.628	0.036	0.735	0.185	0.159	**1.000**	0.647	TI5	0.285	0.074	0.151	0.643	0.203	0.896	0.644
ISR	0.746	0.097	0.036	0.109	0.401	0.141	0.035	TI6	**0.988**	**1.000**	0.503	0.044	0.114	0.043	0.059
NO	0.034	0.019	0.024	0.084	0.018	0.026	0.083	TI7	0.657	0.034	0.150	0.709	**1.000**	**1.000**	0.039
FGI	0.560	**0.998**	0.304	0.044	0.059	0.292	0.460	TI8	0.269	0.042	0.592	0.139	0.068	0.185	0.045
MSI	0.646	**1.000**	**1.000**	**0.943**	0.844	0.491	0.032	TI9	0.447	0.021	0.839	0.329	0.026	0.457	0.099
VS	0.590	0.554	0.036	0.194	0.460	0.153	0.039	TI10	**0.954**	**0.997**	0.091	0.277	**0.924**	0.052	0.041
TI	0.126	0.027	0.374	0.127	0.296	0.149	0.048	TI11	**1.000**	0.018	0.729	**0.995**	0.710	**0.933**	0.055
BB	0.022	0.217	0.657	0.836	0.068	0.812	0.027	TI12	0.317	0.036	0.138	0.747	0.250	**0.909**	**0.992**
BOOK	0.034	0.034	0.650	**1.000**	**0.999**	0.219	0.023	TI13	0.253	0.056	0.386	0.204	0.591	0.209	0.083
BILL	0.087	0.026	0.057	0.745	**0.998**	0.075	0.068	TI14	0.631	0.018	0.108	0.872	0.284	0.062	0.034
PPI	0.436	0.031	0.110	0.037	0.100	0.244	0.753	TI15	0.060	0.031	0.516	0.237	0.076	0.070	0.038
ES	0.039	0.021	0.028	0.346	0.039	0.024	0.032	VS1	0.297	0.021	0.159	0.037	0.591	0.315	**0.999**
ESA	0.245	**0.999**	0.027	0.037	0.060	0.184	0.020	VS2	0.096	0.028	0.018	0.030	0.035	0.395	0.069

- The number of main determinants identified differ, ranging from 5 (6-step-ahead) to 13 (3-step-ahead) predictors. The PIP of each predictor also varies in a large degree over different horizons.

→ The potential risk of the convention method: using the same set of predictors or gives the same weight to a particular predictor.

Table 4 PIP over various prediction horizons

$h=$	0	3	6	9	12	18	24	$h=$	0	3	6	9	12	18	24
EIN	0.053	**1.000**	0.352	0.036	0.044	0.087	0.043	VS3	**0.995**	0.775	0.038	0.025	0.065	0.130	0.027
PPI1	0.504	**0.903**	0.041	0.031	0.033	0.179	0.528	VS4	0.023	0.089	0.085	0.723	0.514	0.028	0.066
PPI2	0.043	0.166	0.088	0.054	0.065	0.221	**0.968**	VS5	0.024	0.022	0.277	0.809	0.146	0.044	0.043
PPI3	0.059	0.019	0.030	0.034	0.787	0.559	**1.000**	VS6	0.020	0.015	0.026	0.023	0.021	0.786	**0.987**
IP1	0.632	0.084	0.768	0.412	0.658	0.517	0.545	VS7	0.061	0.058	0.039	0.019	0.026	0.021	0.039
IP2	**0.971**	0.259	0.046	0.082	0.055	0.656	0.025	VS8	**0.995**	0.018	0.052	0.061	0.024	**0.933**	0.714
IP3	0.083	0.038	0.183	0.071	0.341	0.810	0.069	VS9	0.034	0.017	0.022	0.218	0.056	0.059	0.319
IP4	0.033	0.021	0.027	0.026	0.094	0.496	0.155	VS10	**0.954**	0.060	0.023	0.021	0.249	0.049	0.896
IP6	0.265	0.030	0.494	0.578	0.535	0.055	0.037	VS11	0.058	0.026	0.515	0.722	0.066	0.062	0.021
IP7	0.294	0.018	0.030	0.030	0.062	0.151	0.026	VS12	0.030	0.028	0.231	0.147	0.110	0.051	0.029
IP8	0.853	0.020	0.035	0.274	**0.981**	0.236	0.876	VS13	0.519	0.149	0.712	0.804	0.075	0.225	0.036
NO2	0.033	0.031	0.059	0.249	0.021	0.046	0.239	VS14	0.024	0.086	0.089	0.283	0.019	**0.960**	0.820
NO7	0.035	0.066	0.025	0.042	0.021	0.017	0.025	VS15	0.050	0.162	0.481	0.026	0.038	0.028	0.079

- SOX: 6 of the 7 horizons
- DJ: 6-month-ahead
- NDQ: 18-month-ahead
- TI: none
- TI1-TI15: 8 of the 15 predictors are identified over various horizons.
  - Too much inventory: raising worries of oversupply (ASP down)
  - Too little inventory: concern for possible industry downturn ahead
- CLI, IP, CS: < 6-month
- CAP, UTL, SIP: > 18-month
- FF: effective variable only for 12- and 18-month

Table 5 A comparison of variable selections

	BMA	MC+	SCAD		BMA	MC+	SCAD
FF	0.455	O	O	NO11	0.081	O	O
CLI	0.206		O	NO12	0.022		
IP	0.213	O		NO14	0.078	O	O
CS	**0.966**	**O**	**O**	NO15	0.017	O	O
SOX	**0.984**	**O**	**O**	TI1	0.084	O	O
NDQ	0.060			TI2	0.028	O	O
DJ	0.169	O		**TI3**	**1.000**	**O**	**O**
CAP	0.668	O	O	TI4	0.309		
SIP	0.708			TI5	0.285	O	
UTL	0.628	O	O	**TI6**	**0.988**	**O**	**O**
ISR	0.746	O	O	TI7	0.657	O	O
NO	0.034			TI8	0.269		
FGI	0.560	O	O	TI9	0.447	O	O
MSI	0.646	O	O	**TI10**	**0.954**	**O**	**O**
VS	0.590			**TI11**	**1.000**	**O**	**O**
TI	0.126			TI12	0.317	O	
BB	0.022	O	O	TI13	0.253		
BOOK	0.034	O	O	TI14	0.631	O	O
BILL	0.087		O	TI15	0.060		O
PPI	0.436	O		VS1	0.297	O	
ES	0.039			VS2	0.096	O	
ESA	0.245	O	O	**VS3**	**0.995**	**O**	
EIN	0.053	O	O	VS4	0.023	O	
PPI1	0.504	O	O	VS5	0.024		
PPI2	0.043			VS6	0.020	O	
PPI3	0.059	O	O	VS7	0.061		
IP1	0.632			**VS8**	**0.995**		
IP2	**0.971**	**O**	**O**	VS9	0.034	O	
IP3	0.083	O		VS10	**0.954**	**O**	**O**
IP4	0.033	O	O	VS11	0.058	O	O
IP6	0.265			VS12	0.030	O	
IP7	0.294	O		VS13	0.519		
IP8	0.853	O	O	VS14	0.024	O	O
NO2	0.033			VS15	0.050	O	O
NO7	0.035						
NO9	0.016	O	O	Variables	10	48	37

To further confirm the main determinants, two high-dimensional shrinkage procedures are considered:

- SCAD: Smoothly chipped absolute deviation (Fan and Li, 2001)
- MC+: minimax concave penalty (MCP) + penalized linear unbiased selection (PLUS) (Zhang, 2010)

- Both are Lasso (least absolute shrinkage and selection operator) type procedures. (Tibshirani, 1996)

0-month-shead:

- MC+ 48
- SCAD: 37
- 8 of 10 main determints from BMA are confirmed by both MC+ and SCAD.

Table 6 Selection of the best-fitting ARMA model

Selection criteria	Model							
	AR(1)	MA(1)	ARMA(1,1)	ARMA(2,1)	ARMA(3,1)	ARMA(4,1)	ARMA(3,1) +SAR(12)	ARMA(4,1) +SAR(12)
SSR	0.323	1.996	0.201	0.100	0.090	0.089	0.063	0.062
AIC	−3.368	−1.553	−3.832	−4.513	−4.600	−4.590	−4.875	−4.873
SBC	−3.330	−1.515	−3.775	−4.437	−4.504	−4.47	−4.774	−4.752
Q(12)	342.74	496.11	192.93	61.85	39.25	39.34	9.12	8.10
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.244)	(0.231)
Q(24)	425.59	683.31	251.11	92.18	45.44	44.59	24.798	26.569
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.160)	(0.087)
Q(36)	442.58	780.72	269.79	111.52	54.788	52.33	30.279	32.385
	(0.000)	(0.000)	(0.000)	(0.000)	(0.007)	(0.010)	(0.503)	(0.350)

SSR is the sum of squared residuals
Q(n) repots the Ljung-Box Q-statistic for the autocorrelations of the n residuals for the estimated model
Significance levels are in parentheses

Table 7 Coefficient estimates of the best-fitting ARMA model

The best ARMA model: ARMA(3, 1) + SAR(12)

Variable	Coefficient	SE	t-statistic	P value
Constant, α_1	0.035	0.043	0.809	0.420
AR(1), β_1	1.021	0.104	9.852	0.000
AR(2), β_2	0.699	0.164	4.259	0.000
AR(3), β_3	−0.761	0.081	−9.436	0.000
SAR(12), β_4	−0.556	0.077	−7.182	0.000
MA(1), τ_1	0.615	0.134	4.587	0.000
$R^2 = 0.98$				

Table 8 A comparison of coefficient estimates

	Best linear model			BMA			BMA			BMA		
	Adjusted $R^2 = 0.97$			Uniform model prior			Binomial model prior			Beta-binomial model prior		
	Estimate		SE	PIP	PM	PSD	PIP	PM	PSD	PIP	PM	PSD
IP	0.679	***	0.156	0.213	0.060	0.305	0.024	0.008	0.092	0.070	0.008	0.173
CS	0.191	***	0.034	**0.966**	0.177	0.056	**0.972**	0.213	0.061	**0.973**	0.201	0.058
SOX	0.092	***	0.009	**0.984**	0.086	0.022	**0.967**	0.093	0.023	**0.978**	0.093	0.022
CAP	0.541	***	0.061	0.668	0.037	0.539	0.661	0.009	0.549	0.659	0.033	0.540
UTL	1.085	***	0.062	0.628	0.424	0.530	0.610	0.415	0.539	0.619	0.418	0.531
ISR	−2.383	***	0.364	0.746	−0.885	0.853	0.390	−0.207	0.314	0.477	−0.358	0.542
VS	−2.096	***	0.388	0.590	−0.339	0.983	0.607	0.359	0.395	0.605	0.229	0.634
PPI1	0.449	***	0.064	0.504	0.200	0.215	0.512	0.222	0.227	0.503	0.206	0.218
IP1	−0.544	***	0.141	0.632	−0.457	0.418	0.543	−0.510	0.517	0.565	−0.482	0.481
IP2	−0.189	***	0.037	**0.971**	−0.258	0.082	0.814	−0.224	0.120	0.894	−0.246	0.105
IP8	−0.347	***	0.041	0.853	−0.256	0.131	**0.922**	−0.308	0.124	**0.909**	−0.296	0.127
TI3	−0.391	***	0.030	**1.000**	−0.387	0.058	**1.000**	−0.405	0.050	**1.000**	−0.398	0.054
TI6	0.118	***	0.028	**0.988**	0.168	0.050	**0.967**	0.178	0.048	**0.983**	0.174	0.046
TI7	0.593	***	0.085	0.657	0.240	0.227	0.294	0.080	0.139	0.368	0.107	0.168
TI8	−1.211	***	0.128	0.269	−0.246	0.451	0.139	−0.107	0.291	0.123	−0.096	0.289
TI9	0.509	***	0.070	0.447	0.157	0.203	0.126	0.045	0.130	0.157	0.052	0.136
TI10	0.260	***	0.034	**0.954**	0.231	0.076	**0.992**	0.249	0.060	0.981	0.247	0.065
TI11	0.775	***	0.045	**1.000**	0.781	0.077	**1.000**	0.773	0.077	**1.000**	0.766	0.074
TI13	1.936	***	0.349	0.253	0.400	0.770	0.026	0.040	0.290	0.074	0.104	0.437
VS1	−0.080	***	0.017	0.297	−0.020	0.034	0.120	−0.008	0.024	0.171	−0.011	0.026
VS3	−0.076	***	0.018	**0.995**	−0.096	0.024	0.872	−0.082	0.040	**0.960**	−0.092	0.031
VS8	0.740	***	0.087	**0.995**	0.639	0.133	**0.982**	0.596	0.160	**0.994**	0.616	0.137
VS10	−0.162	***	0.030	**0.954**	−0.145	0.050	0.808	−0.122	0.070	0.891	−0.134	0.061

Best linear model (BLM):

- Chosen from BMA
- $R^2 = 0.97$
- < 10 of 23 predictors with a 1% significance level are classified as main determinants under various BMA model priors.

Table 9 Out-of-sample forecasting

Horizon	RW		Relative MAE					Relative MSE				
(months)	MAE	MSE	ARMA	BLM	MC+	BMA	BMA*	ARMA	BLM	MC+	BMA	BMA*
0	0.0355	0.0024	0.74	1.53	1.35	1.41	1.38	0.51	1.99	1.66	1.67	1.78
3	0.1276	0.0302	0.84	0.57	0.56	0.56	0.46	0.69	0.35	0.31	0.32	0.22
6	0.2100	0.0728	0.66	0.52	0.48	0.48	0.39	0.40	0.27	0.23	0.22	0.15
9	0.2678	0.1138	0.46	0.39	0.34	0.37	0.24	0.19	0.16	0.13	0.11	0.06
12	0.2959	0.1332	0.31	0.36	0.32	0.32	0.21	0.11	0.14	0.11	0.11	0.05
18	0.3068	0.1178	0.52	0.41	0.33	0.35	0.28	0.37	0.23	0.14	0.16	0.10
24	0.2838	0.0979	0.59	0.42	0.39	0.40	0.36	0.37	0.26	0.17	0.21	0.16

Relative errors are the ratios of the respective models' MAE or MSE to those of the random walk (RW) model
ARMA the best-fitting ARMA model; *BLM* the best linear model; *MC+* Zhang's (2010) nearly unbiased variable selection under minimax concave penalty; *BMA* the BMA estimation under the uniform model prior with 70 potential predictors; *BMA** the BMA model under the uniform model prior with 70 potential predictors and their respective 3 lags (i.e., 280 predictors in total)

In sample: 1995:05-2009:02
Out-of-sample: 2009:03-2012:10
RW (random walk) vs. ARMA, BLM, MC+, BMA, BMA*
MAE: mean absolute prediction error
MSE: mean squared prediction error

1. ARMA is better than RW: 16-69% (MAE), 31-89% (MSE)
2. BLM is the worst and ARMA is the best in the moment-term.
3. BMA is better than BLM and ARMA.
4. BMA ties with MC+.

Table 10 Diebold-Mariano (DM) test

Horizon (Months)	RW MAE	RW MSE	ARMA MAE	ARMA MSE	BLM MAE	BLM MSE	MC+ MAE	MC+ MSE
BMA versus								
0	0.0144*	0.0016	0.0237***	0.0028***	−0.0044*	−0.0008***	0.0019	0.00004
3	−0.0561*	−0.0205	−0.0362*	−0.0110	−0.0006	−0.0007	0.0002	0.0004
6	−0.1096**	−0.0565*	−0.0378*	−0.0125*	−0.0089	−0.0032***	0.0006	−0.0003
9	−0.1639***	−0.0954**	−0.0181	−0.0284	−0.0060	−0.0002	0.0128	0.0033**
12	−0.1998***	−0.1185**	0.0056	−0.0001	−0.0091**	−0.0042***	0.0018	0.0004
18	−0.1994***	−0.0988***	−0.0523	−0.0242	−0.0195***	−0.0079***	0.0049	0.0026
24	−0.1716***	−0.0771***	−0.0544**	−0.0157**	−0.0080	−0.0038*	0.0026	0.0044
BMA* versus								
0	0.0134	0.0019	0.0227***	0.0031*	−0.0054	−0.0005	0.0009	0.0003
3	−0.0687*	−0.0237	−0.0488**	−0.0142*	−0.0132	−0.0039	−0.0123	−0.0028
6	−0.1281***	−0.0617**	−0.0563***	−0.0177**	−0.0274***	−0.0084**	−0.1795	−0.0055
9	−0.2022***	−0.1065**	−0.0564***	−0.0140**	−0.0323***	−0.0109**	−0.0255***	−0.0078***
12	−0.2326***	−0.1268**	−0.0272	−0.0084	−0.0420***	−0.0125***	−0.0310***	−0.0079**
18	−0.2194***	−0.1056***	−0.0723*	−0.0314*	−0.0395***	−0.0150**	−0.0150	−0.0046
24	−0.1803***	−0.0825***	−0.0631***	−0.0211***	−0.0167	−0.0093	−0.0061	−0.0010

RW the random walk model; *ARMA* the best-fitting ARMA model; *BLM* the best linear model; *MC+* Zhang's (2010) nearly unbiased variable selection under minimax concave penalty; *BMA* the BMA model under the uniform model prior with 70 potential predictors; *BMA** the BMA model under the uniform model prior with 70 potential predictors and their respective 3 lags

DM test:

Evaluate the significance of the differences in prediction accuracy.

Conclusions from Liu and Weng (2017)

- The present study shows how the well-developed BMA approach which considers the model uncertainty can be easily applied to identify the main determinants of the semiconductor industry cycle over various prediction horizons from a large number of potential predictors.
- The Philadelphia Semiconductor Index and total inventories in the downstream industries may provide clear signals on the industry ups and downs across various time horizons. These main determinants identified by BMA are also supported by recently developed high-dimensional shrinkage procedures, MC+ and SCAD.
- The BMA model generally gives more accurate predictions than the competing models. This superior forecasting performance is consistently verified across different prediction horizons, except for the relatively short horizons (the 0- and 3-month-ahead forecasts).

Thank you for your participation!

Comments are most welcome!