THE EFFECT OF GLOBAL COMPETITION ON INNOVATION IN THE SEMICONDUCTOR INDUSTRY

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Abstract: There has been a dramatic shift in the location of semiconductor production over the last 20 years, with an increasing share of global production taking place in the Asia Pacific region. We investigate the impact that this shift has had on the innovative behavior of semiconductor manufacturers in the rest of the world. Traditional North-South innovation models indicate that North firms would increase their innovation as production increases in the South. We find that R&D spending by North firms does indeed increase as semiconductor production shifts to Asia Pacific. However, we find no evidence to indicate that the volume of patenting by North firms increases as a result.

Keywords: Semiconductors, Innovation, Patents

JEL Classification: O3, F6

1. Introduction

The global semiconductor industry has undergone a sea-change, as production has shifted away from countries such as the U.S., Japan, Germany, and the Netherlands, to Asian Pacific countries such as Malaysia, Taiwan, South Korea, and China. In 1991, approximately 15% of global semiconductor revenues came from production in Asian Pacific countries (excluding Japan); in 2014, that share was approximately 58% (WSTS, 2015). Much of this growth in semiconductor production has come from China. China's share of global semiconductor production grew from 2.4% in 2000 to 21.5% in 2013 (PwC, 2014).

The semiconductor industry has a high level of innovation. In 2014, semiconductor firms worldwide spent approximately $56 billion on research and development (R&D) (ISInsights, 2014), and from 2010-2014 over 160,000 semiconductor-related patents were issued by the USPTO (www.uspto.gov).

In this paper we look at how the innovative activity of semiconductor firms has changed in response to the shift in global production towards Asia Pacific. The "North-South" theory of product cycles based on the endogenous growth models of Grossman and Helpman (1991a, 1991b) indicates that as manufacturers in the South increase their production, manufacturers in the North will increase their rate of innovation in order to stay ahead of the new competition. However, empirical studies do not fully support the theoretical results. Simons and Isely (2014), for example, find that increased automobile production in the South results in a decrease in automobile innovation in the North. The question we seek to address here is: how has the innovative behavior of semiconductor firms responded to the rapid global shift in semiconductor production?

2. Methodology

2.1. Data

We obtain data on individual firm's production revenues and research and development (R&D) spending by company from the EDGAR database or from each company's annual reports, and convert into real 2009 values using the U.S. GDP Deflator (available at www.bea.gov). We obtain data on regional semiconductor production from the World Semiconductor Trade Statistics website (www.wsts.org). The time period for our study is 1991-2013.

We split semiconductor firms into two groups. Group 1 consists of semiconductor firms located outside of Asia Pacific (other than Japan). This group includes firms located in the U.S.A., Japan, Germany, the Netherlands, etc. Group 2 consists of semiconductor firms located in Asia Pacific (excluding Japan). This group includes firms located in South Korea, Malaysia, Taiwan, China, etc.

We restrict our choice of Group 1 firms using the following criteria: The firm must (1) be among the top 20 largest semiconductor producers in 2013 (according to the industrial research company IHS Technology), (2) describe itself as a semiconductor company or reports R&D separately for the semiconductor division of the company, and (3) have a minimum of 10 consecutive years of patenting, semiconductor sales, and semiconductor R&D, within the time period of our study.

Using these criteria, our Group 1 firms are: Advanced Micro Devices, Broadcom, Freescale, Infineon, Intel, Marvell, Micron Technology, Nvidia, Qualcomm, Renesas, Sandisk, STMicroelectronics, Texas Instruments, and Toshiba. No firm-specific data is needed for Group 2. However, the aggregate data for Group 2 reflects the production of companies such as SK Hynix, MediaTek, PowerChip, HiSilicon Technologies, TSMC, and Malaysian Pacific Industries.

We use R&D spending to measure the input in the innovation process, and follow the extensive literature that uses patent data to measure the output of the process (see, for example, Pavitt and Soete, 1997, and Jaffe, Fogarty, and Banks, 1998). We obtain all our patent data from the U.S. Patent and Trademark Office's online patent database (http://www.uspto.gov), counting the number of granted U.S. patents from the Current U.S. Classifications 438 (Semiconductor Device Manufacturing: Process), 257 (Solid State Devices), and 174 (Electricity: Conductors and Insulators). Because the patent application process can take several years we test if there is a significant effect from patents filed in 2013 that have not yet been granted by running a specification of the base model with a 2013 dummy variable. Because this dummy is not significant, we do not include it in the specification of the model shown below.

2.2. Model

We use two related models. First, we model the amount of money spent on R&D as dependent on the sales of the firm, the sales of all of its Group 1 competitors, and the sales of all of the Group 2 competitors. Then, in a parallel fashion to (Simons ans Isely, 2014), we model patenting as dependent on those same sales variables as well as R&D spending. We try three different specifications for these models: Negative binomial, log-log, and Poisson. The results for both models are consistent for all three specifications. We report here only the results of the log-log specification for space considerations. Thus, our two Cobb-Douglas style production functions are:

$R\&D_{kt} = f(SALES_{kt}, SALES_{G1t} - SALES_{kt}, SALES_{G2t})$ (1)

$PATENTS_{kt} = f(SALES_{kt}, SALES_{G1t} - SALES_{kt}, SALES_{G2t}, R\&D_{kt})$ (2)

where

- Subscript k designates individual Group 1 firms, and t is years.
- $R\&D_{kt}$ is the natural log of firm k's spending on research and development in year t.
- $SALES_{kt}$ is the natural log of semiconductor sales by firm k in year t.
- $SALESG_{1t}$ is the natural log of semiconductor sales by all of Group 1 in year t.
- $SALES_{G2t}$ is the natural log of semiconductor sales by all of Group 2 in year t.
- Year is a trend variable.
- $PATENTS_{kt}$ is the number of granted semiconductor patents that were applied for in the U.S. in year t, where firm k is the assignee.

3. Results

Tables 1 and 2 give the regression results for the two model specifications.

In Model 1, the coefficients indicate that Group 1 firms spend more on R&D as their own sales increase, as the sales of their Group 1 competitors decreases, and as the sales of their Group 2 competitors increases. All three of these coefficients are significant at the 99% level.

In Model 2, the coefficients indicate that, with statistical significance, the patenting output of Group 1 firms increases as the sales of their Group 1 competitors increases, and as their own R&D spending increases. However, the coefficient on Group 2 sales is negative and not significant. Ceteris Paribus, the number of Group 1 patents does not increase as Group 2 production increases.

Recall that our focus in this paper is to see if the innovative behavior of Group 1 firms is influenced by competition from firms in Group 2. Taken together, these two models indicate that as semiconductor production increases in Asia Pacific, the representative Group 1 semiconductor producer increases its R&D spending, but has no additional patenting.

4. Summary and Conclusions

The above results indicate that we are unable to find conclusive support for the traditional North-South innovation model, which predicts that greater competition from the South will encourage North firms to innovate more. Our results indicate *some* support, in that greater competition from the South encourages more R&D spending by firms in the North. However, the additional R&D spending incurred due to the increase in South production does not have a statistically significant impact on the quantity of patenting by North firms. So firms are spending more on research and development, but they end up not patenting more.

What could explain these results? We put forward two possible explanations: (1) Firms are deliberately choosing to not patent some of their innovations; (2) Firms are patenting a small number of high quality and/or "big" innovations rather than a large number of low quality and/or "small" innovations.

The first explanation would apply if a firm believed that the benefit of keeping the specifics of its innovation secret outweigh the benefits of patent protection. This would be more likely if intellectual property right protection is lacking in certain countries. The problems associated with enforcing intellectual property protection in China add validity to this explanation.

One way to investigate the second explanation is to look at the number of citations that a patent receives. Presumably, a high quality or big innovation would have a more significant impact on future research and thereby end up being cited frequently by other patents. However, it would be difficult to capture any effect of the recent rise in semiconductor production in China due to the lags in the patent approval process and the additional time lag before a high quality innovation is cited by other patents.

While our results do not allow us to definitively identify the cause of the mixed support for North-South innovation models, they do suggest potential directions for additional research.

Endnotes

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Table 1. Regression Results for Model 1

Dependent Variable: $R\&D_{kt}$	
$SALES_{kt}$	0.913** (18.18)
$SALES_{G1t}$ - $SALES_{kt}$	-0.455** (4.39)
$SALES_{G2t}$	0.230** (3.15)

Absolute value of z statistics in parentheses.** significant at 1%.

Table 2. Regression Results for Model 2

Dependent Variable: $PATENTS_{kt}$	
$SALES_{kt}$	-0.172 (0.64)
$SALES_{G1t}$ - $SALES_{kt}$	0.825* (1.87)
$SALES_{G2t}$	-0.340 (1.52)
$R\&D_{kt}$	0.815** (2.66)

Absolute value of z statistics in parentheses. * significant at 10%, ** significant at 1%.