Navigating Leadership position in Semiconductor Industry

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The aim of this study is to propose an empirically validated framework consisting of internal and external factors that can help drive a company to a leadership position in semiconductor industry. The study highlights distinct drivers namely Technological Adeptness (TA), Production Excellence (PE), Sustainable Manufacturing (SM), Digital Economy (DE) and Techno-nationalism (TN) as significantly impacting the leadership position of a company in semiconductor industry. Survey results from 250 respondents used for statistical analysis. This research study will be valuable for semiconductor companies, similar technology companies operating in global environment, service providers, Industry bodies and government policymakers.

Keywords: Semiconductor, Technical Adeptness, Production Excellence, Sustainable Manufacturing, Techno-nationalism, Digital Economy

1. Introduction

Semiconductor industry is expected to grow to USD 1 Trillion by 2030 as per Deloitte Report (2022). The emerging and futuristic technologies like Artificial Intelligence (AI), Telecommunications, Automotives are betting heavily on semiconductors. This drives an important question as to what factors drive the leadership of a company in semiconductor industry. Semiconductor industry has dependencies spread across the geographies as value chains have emerged globally (Lamsal et. all., 2023). Semiconductor devices produced by this industry are used across various commercial, military and space applications thus demanding a strategic importance status from governments across various nations (Wang & Lin, 2021). Governments across the globe exercise control over the market for geopolitical gains (Capri, 2020). Despite the advances in research area, critical gaps remain with respect to the understanding on what factors are key drivers for leadership position in industry. To address this gap, this study proposes a conceptual framework consisting of five critical drivers for leadership position namely, Technological Adeptness (TA), Production Excellence (PE), Sustainable Manufacturing (SM), Digital Economy (DE) and Techno-nationalism (TN). This research paper follows an integrative approach that combines various constructs contributing to building a theoretical framework for internal and external factors that impact the leadership position. An online research survey was designed, circulated and responses were collected from experts in semiconductor industry. Statistical analysis was performed on the data from 250 respondents using SMARTPLS 4.0 tool. Structural Equation Modelling (SEM) was used to validate various hypotheses proposed as part of the study. This paper is built upon research study conducted as part of doctoral thesis.

2. Research Problem , Research Objective , Research Methodology

With the rising strategic importance of semiconductor industry, the importance of the question about what internal and external factors drive the leadership of a company in semiconductor industry have increased. Literature review helped identify five main drivers or factors that can help drive leadership position of a company in semiconductor industry. The factors identified for empirical validation were (a) Technological Adeptness (TA) (b) Production Excellence (PE) (c) Sustainable Manufacturing (SM) (d) Techno-nationalism (TN) and (e) Digital economy (DE). The research objective of this study is to empirically test the relationship between variables and validate the proposed hypothesis. Literature review was done with existing literature on semiconductor industry through reliable sources like ProQuest, EBSCO, Google scholar etc. Gaps were mapped as independent variables to be considered critical for a company to gain a leadership position in semiconductor industry. Each of the independent variable was further identified by five sub-variables each based on the literature review. A conceptual model was proposed based on the independent variables, sub-variables, dependent variables and outcome measures. The conceptual model depicts possible relationship of independent variables, sub-variables and dependent variables. Survey questionnaire was derived based on questions build around each of the sub-variables. Statistical analysis carried out on the responses received as part of the research survey was used to validate the proposed conceptual model.

3. Literature Review

Literature review helped identify five main drivers or factors that can help drive leadership position of a company in semiconductor industry.

3.1 Technological adeptness (TA)

Until recently the semiconductor industry was driven by Moore's law which in recent times has started to reach its physical limits resulting in slowdown (Bespalov et al., 2022). Due to this slowdown, researchers have now started to focus on developing alternatives for semiconductor chip manufacturing. Semiconductor industry strives for innovation due to the ever-increasing demand for faster and powerful chips to help boost the performance of cutting-edge equipment in the market (McKinsey, 2022). Innovative feature offering helps differentiate the products from competition in a high-growth and leading technology market segments (Buccieri et al., 2023). Few OEMs and hyperscale compute giants have started to invest on in-house chip design capability so that they could differentiate their offerings with customizations suitable for their own product lines. This would result in increased demand for semiconductor talent and putting more constraints on already scarce talent market (Burkacky et al., 2022). Companies should work on building their own brand image in order to attract and retain talent in the competitive market (McKinsey, 2022). Partnership with academic institutions could be one of the solutions towards solving the talent crunch (Pearson et al., 2023). This partnership will benefit students to better equip themselves with skills required for the industry and make them more employable (McKinsey, 2022). Industry bodies should consider establishing an ecosystem that could help handle the increased complexity in semiconductor design, shifts in the value chain and the increased competition for talent (Pennisi, 2022). Collaboration could also shape in the way that one of the partners could develop IP (intellectual property) block that could be used and leveraged by many other partners in the ecosystem (London, 2023). Various ethical and trust issues have emerged with the advancement in the Artificial Intelligence (AI) space. AI can perform a wide range of tasks for consumers and hence it becomes very crucial that the products built with AI capabilities duly reflect the priorities of consumers and values system suitable to their application (Du & Xie, 2021). AI Products are increasingly making an influence on decision-making process of consumers and thus it is crucial to integrate ethical values in product designs (Etzioni, & Etzioni, 2017) to gain their trust.

3.2 Production Excellence (PE)

Production excellence helps to get a competitive advantage over others through various means like operational profitability, innovation and quality benchmarks. Semiconductor Fab involves a heavy capital expenditure and operations expenditure and thus cost reduction is one of the main targets to improve upon productivity, profitability and competitiveness (Chien et al., 2024). Focus upon quality and cost reductions can help flourish semiconductor ecosystem (Singh & Misra, 2024). Potential improvements in the process can be driven through deployment of quality functions in the organization. In semiconductors, silicon's reliability and quality is also defined by the silicon packaging technology. This packaging technology might deliver considerable cost savings for companies in future as per McKinsey (2022). As the demand for semiconductor products increase and the technology is reaching its physical limits, there is increased interest and investment in advanced packaging technology (Das & Mahajan, 2024). For semiconductors, it is also critical to focus on product reliability and hence reliability analysis forms an integral part of the product development cycle (Cabanes et al., 2021). Being proactive and fixing issues upfront as part of design phase is always beneficial especially with respect to cost, quality and reliability (Cabanes et al., 2021). Cost optimization initiatives and quality improvements on a continuous basis helps drive the production excellence (Singgih et al., 2021). Due to increased processing power of digital platforms, it is possible to implement integrated and related strategic decision making around capacity planning, pricing, demand projections and cost structure analysis (Chien et al., 2024). Smart manufacturing can thereby help develop an effective ecosystem to reduce manual errors, improve yields, reduction in energy consumption and effective capacity utilization (Sahoo & Lo,2022).

3.3 Sustainable Manufacturing (SM)

Semiconductor manufacturing can face a great challenge with respect to sustainable development due to the fact that it is the highest consumer of pure water, energy and a range of chemicals for its production process (Wang et al.,2023). It needs to focus on waste water treatment that gets generated as part of fabrication process and discharged into the environment (Sim et. all, 2023). The mass of chemicals and water consumed as part of the semiconductor fabrication far outweighs the mass of end-product (Mullen & Morris, 2021). Moving towards sustainable supply chain can help in moving towards the circular economy goals for semiconductor manufacturer (Samadi et al., 2018). There is not much of information yet on the implications of semiconductor fabs on sustainability and circular economy (Chien et. all, 2024). There are costs associated with environmental sustainability and regulatory requirements which the semiconductor manufacturing industry needs to account (Mullen & Morris,2021). As part of reducing CO_2 footprint, many firms are implementing sustainable practices in their operations (Ma et al., 2022). Also, green sourcing and sustainable supply chains needs to be considered by semiconductor manufacturers to meet the goals of emission reduction (Ma et al., 2022). Supply chain managements should implement and integrate the principles of sustainable supply in order to propagate the circular economy (Samadi et al., 2018). In recent times, many fabless companies have emerged which maintains higher functions (design engineering) and the production is outsourced to third party vendors like TSMC, Samsung, Global foundries etc. (Ruberti, 2023). With the increased processing power of digital ecosystem and technology advancement, semiconductor manufacturers should implement new mechanisms for efficiency improvements and yield improvements (McKinsey, 2022). For the overall benefit of semiconductor industry, the industry associations could play a pivotal role in providing long term technology roadmap clarity and facilitation of collaborative ecosystem between different industry players including the research institutes (McKinsey, 2022). In the roadmap published with experts from developed countries like US, Korea, Japan, Taiwan and Europe, there is dedicated chapter on ESH (environment, safety and health). EU

(European union) has come forward with a preliminary version of Chips Act which focuses on lack of environmental considerations and have planned for 43 billion euros investments by 2030 (Chips act for Europe, 2022).

3.4 Techno-Nationalism (TN)

Techno-nationalism refers to state's engagement in hi-tech industries as part of support to domestic companies and help them maintain a dominant position in global value chain thereby displaying diplomatic power projections (Park, 2023). High end technologies like semiconductors are increasingly becoming a subject of geopolitical tension. Techno-nationalism links innovation capabilities and technology ownership as a matter of national identity, security and social stability for a country (Salehi et al., 2024). Some countries are linking supply chains to national security wherein sanctions are imposed on import or export of certain goods and technologies to and from specific countries (Yan, 2023). This kind of activities impacts the global supply chain activities for multinational companies and like noted earlier, semiconductor products are the result of global collaboration. United States had imposed sanctions on export of chip manufacturing equipment, Hi-Tech semiconductors and components meant for supercomputers to China (Mishra, 2023). There are certain policies driven by governments in the western world taking into consideration the concept that technology is a distinctive product that should be owned and dominated by the western world primarily the United States (Yan, 2023). US CHIPS Act appropriates US$ 52.7 Billion over a period of five years for investments in Research & Development for semiconductors, manufacturing incentives and expansion of various institutes of national importance (Mishra, 2023). EU has initiated a series of security measures with EU Chips Act proposal which marks the shift of EU's strategy from liberal globalization to techno-nationalism (Sprokholt, 2024). Due to ubiquitous nature of semiconductor chips and its projected demand growth over the next decade global supply chains and value chains are expected to be strained and hence securing a healthy share of it has gained priority for all nations (Sprokholt, 2024). Public procurement policies in some countries discretionally favors products with indigenous technology and support from local ecosystem favors funding domestic R&D (Diegues & Roselino, 2023).

3.5 Digital Economy (DE)

Semiconductors are ubiquitous and forms a fundamental platform for digital economy (Karmal,2022). Economic and social lives of people are mediated by a web of interconnected devices that carry data over digital fabric (Tyson et al., 2023). Digital tools and medium are re-shaping the opinions of people and sometimes can drive negative implications like cyberattacks on critical networks, misinformation campaigns or surveillance issues (Tyson et al., 2023). On one side computer and networking devices provide convenience but on other side there are emerging security concerns and issues that are becoming more serious. Thus, information security requirements for semiconductor devices are becoming more and more critical and complex (Zhao et al., 2015). It is essential for semiconductor companies to setup IP Strategy office looking into patents, copyrights, trade secrets and trademarks to keep the business competitive and ensure compliance of all the products and services being offered by the company (Nachev et al., 2024). Also, IP Strategy needs to be reviewed and updated on regular basis to align with the market and evolving ecosystem (Nachev et al., 2024). Cross border transfer of technology and knowledge is very crucial for semiconductor companies for its development. Semiconductor supply chain is fragmented across the globe with different countries owning a part of the supply chain and thereby bringing in globally integrated supply chain (Goldberg et al., 2024). Very little is known about ethical principles that should be the guiding principle for design, development, and deployment of trustworthy applications using devices that has semiconductors at its heart (Nguyen et al., 2023). Designers who are part of design activities needs to have a focus on ethics and engage in ethically-aware design practices (Chivukula et al., 2021). In turbulent times, one of the strategies that can be deployed is regularly introducing new products in the market (Roh & Park, 2023).

4. Conceptual Framework

The proposed conceptual model in Figure.1 represents the independent variables, sub-variables, dependent variable, and outcome measures depicting the possibility of inter-relationship of independent variables with dependent variables. This forms the base conceptual model, the validity of which was intended to be established through the statical analysis of research survey responses.

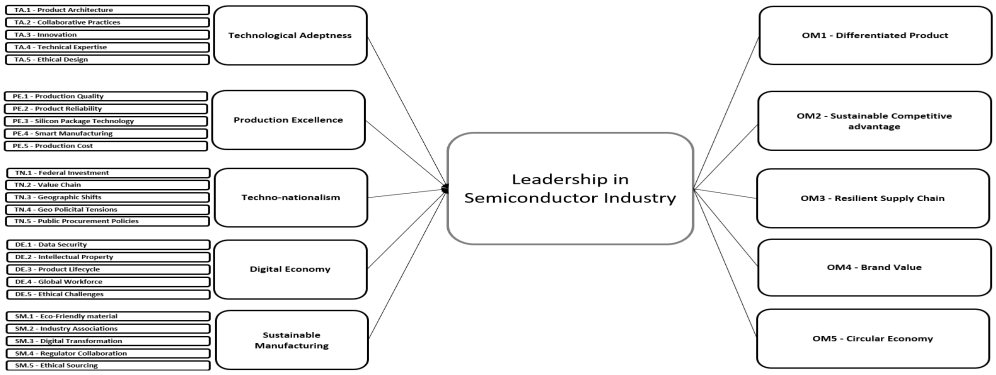

Figure 1 *Proposed Conceptual Model – Leadership in Semiconductor Industry*

5. Sampling & Respondent Profile

For validating the conceptual model, data collection was done through an online research survey using a questionnaire. The final questionnaire was posted online using Google Forms. The survey was circulated to a wider set of people who had experience working in semiconductor industry. This included people with varying range of experience in industry, different geographies, and varying level of decision-making authority in their existing role. There were no specific preferences on either the age, or gender or geography while designing the survey or while seeking response from the participants.

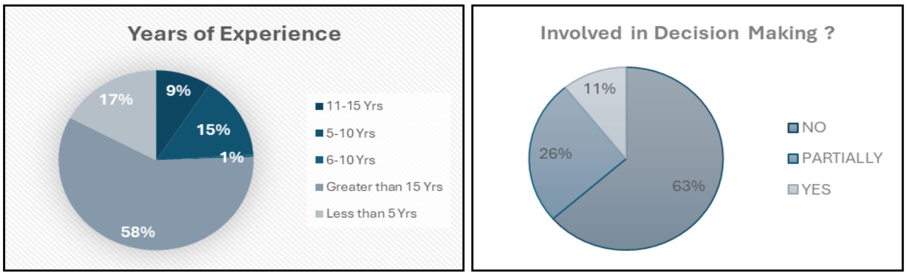

Figure 2 *Respondent Profile*

Approximately 850 people were contacted through email and social networking mediums like LinkedIn and WhatsApp. The survey received a total of 250 responses over a period of five weeks. As per Hair et al. (2022), the minimum number of samples (n min) can be given by the Table I equation where (p min) is the minimum magnitude of the path coefficient in PLS Model. Sample size of 250 is thus considered adequate for this research survey.

Table I *Sample Size Criteria. Source: Hair et al. (2022)*

p_{min}	Significance Level		
	1%	**5%**	**10%**
0.11 – 0.2	251	115	113

6. Structural Equation Modelling (SEM)

Structural Equation Modelling (SEM) is a popular tool to model multivariate relations and test out the theories (MacCallum & Austin, 2000). Structural equation modelling was used to model the relationship between dependent variable and independent variables.

6.1 Construct Reliability

SmartPLS Software provides three construct reliability quotients as shown in Table II.

Table II *Construct Reliability Results from Smart PLS4 Tool Analysis.*

Construct Reliability	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)
DE	0.756	0.769	0.836
OM	0.904	0.905	0.929
PE	0.861	0.866	0.900
SM	0.828	0.837	0.879
TA	0.730	0.746	0.830
TN	0.821	0.826	0.874

The Composite reliability (rho_c) values of all the constructs are above 0.7 and in most cases at or close to 0.9 which indicates a very good reliability. The Cronbach's Alpha values for all the constructs in the table are greater than 0.7 which again indicates a consistency of constructs. The Dijkstra–Henseler's rho (rho_a) values in the table for all the constructs are greater than 0.7 which reconfirms the indication of good reliability. Overall, considering the outcome of the construct reliability test from the values of all constructs in the table, it is confirmed that the reliability level of this study is good or excellent.

6.1.1 Scale Validity

This study considered three primary ways to check the validity of the model (a) Convergent Validity (b) Discriminant Validity (c) Cross loading.

6.1.1.1 Convergent Validity

AVE figures have been examined to validate the convergent validity of the proposed model as shown in Table III. Since all the values in the table are more than 0.5 it indicates that the model has convergent validity.

Table III *AVE Results for the Constructs from Smart PLS4 Tool Analysis*

Construct	**Average variance extracted (AVE)**
DE	0.506
OM	0.723
PE	0.643
SM	0.594
TA	0.551
TN	0.582

As per Anderson & Gerbing (1988) convergent validity can be observed using Maximum Likelihood loading values as shown in Table IV.

Table IV *Maximum Likelihood Loading for each Indicator Result from Smart PLS4 tool Analysis*.

	DE		**OM**		**PE**
DE1	0.674	**OM1**	0.793	**PE1**	0.759
DE2	0.797	**OM2**	0.845	**PE2**	0.857
DE3	0.691	**OM3**	0.844	**PE3**	0.834
DE4	0.710	**OM4**	0.883	**PE4**	0.795
DE5	0.676	**OM5**	0.883	**PE5**	0.760

	SM		**TA**		**TN**
SM1	0.759	**TA1**	0.740	**TN1**	0.736
SM2	0.794	**TA2**	0.793	**TN2**	0.780
SM3	0.668	**TA3**	0.656	**TN3**	0.714
SM4	0.790	**TA5**	0.773	**TN4**	0.794
SM5	0.834			**TN5**	0.788

Based on analysis of 19 determinants, the value of 19 determinants is greater than 0.7. The are five determinants having values < 0.7 (i.e. DE1 = 0.674, DE3 = 0. 691, DE5 = 0.676, SM3 = 0.668, TA3 = 0.656). However, when rounded off all the determinants are rounding off to 0.7. Thus the proposed model clears the convergent validity test safely as can be observed from the values of various determinants represented in above tables.

6.1.1.2 Discriminant Validity

Smart PLS 4 offers Fornell and Larcker (1981) as a criterion to check the discriminant validity as represented in Table V.

Table V *Discriminant Validity Result from Smart PLS4 Tool Analysis*

	DE	**OM**	**PE**	**SM**	**TA**	**TN**
DE	**0.711**					
OM	0.702	**0.850**				
PE	0.635	0.787	**0.802**			
SM	0.516	0.702	0.534	**0.771**		
TA	0.604	0.714	0.722	0.557	**0.742**	
TN	0.623	0.762	0.681	0.562	**0.650**	**0.763**

Based on the table, the discriminant validity holds good since square root of AVE Values represented by the diagonal values for each row and column are greater than any of the inter-construct shown by non-diagonal values for each row and column. Thus, discriminant validity is said to have been established for the model.

6.1.1.3 Validating Scale through Cross Loadings

Cross-loading validation results from SmartPLS tool are shown in Table VI.

Table VI *Cross-Loading Validity Result from Smart PLS4 Tool Analysis*

	DE	**OM**	**PE**	**SM**	**TA**	**TN**
DE1	**0.674**	0.430	0.412	0.291	0.392	0.434
DE2	**0.797**	0.615	0.593	0.401	0.474	0.543
DE3	**0.691**	0.480	0.421	0.357	0.362	0.371
DE4	**0.710**	0.475	0.398	0.367	0.387	0.396
DE5	**0.676**	0.471	0.398	0.416	0.526	0.450
OM1	0.618	**0.793**	0.657	0.529	0.644	0.627
OM2	0.575	**0.845**	0.689	0.556	0.632	0.601
OM3	0.554	**0.844**	0.617	0.653	0.552	0.690

	DE	OM	PE	SM	TA	TN
OM4	0.627	**0.883**	0.728	0.578	0.611	0.650
OM5	0.610	**0.883**	0.655	0.664	0.598	0.668
PE1	0.473	0.566	**0.759**	0.431	0.546	0.523
PE2	0.553	0.715	**0.857**	0.451	0.685	0.599
PE3	0.524	0.664	**0.834**	0.413	0.546	0.559
PE4	0.502	0.620	**0.795**	0.475	0.601	0.509
PE5	0.490	0.578	**0.760**	0.368	0.504	0.535
SM1	0.372	0.472	0.320	**0.759**	0.396	0.381
SM2	0.350	0.556	0.365	**0.794**	0.393	0.410
SM3	0.426	0.481	0.485	**0.668**	0.395	0.403
SM4	0.379	0.554	0.405	**0.790**	0.431	0.452
SM5	0.459	0.624	0.474	**0.834**	0.516	0.507
TA1	0.420	0.463	0.510	0.362	**0.740**	0.399
TA2	0.451	0.560	0.622	0.445	**0.793**	0.488
TA3	0.357	0.405	0.388	0.349	**0.656**	0.426
TA5	0.538	0.648	0.589	0.476	**0.773**	0.590
TN1	0.446	0.558	0.496	0.426	0.460	**0.736**
TN2	0.572	0.645	0.607	0.447	0.576	**0.780**
TN3	0.407	0.466	0.384	0.391	0.444	**0.714**
TN4	0.474	0.630	0.583	0.406	0.478	**0.794**
TN5	0.460	0.582	0.494	0.472	0.509	**0.788**

The results show that the loading of the determinants on their respective constructs (indicated by bold values) are greater than cross loading on all other constructs. This result establishes that the proposed model does not have any cross-loading.
Overall, based on observations listed in above sections, it can be concluded that the proposed model passes the reliability and validity tests, and model can be considered reliable and valid.

6.1.2 INDICATOR MULTICOLLINEARITY

The Variance Inflation Factor (VIF) in a regression analysis is the measure of multicollinearity. Table VII represents the outcome of Multicollinearity test from Smart PLS 4.

Table VII *Multicollinearity Test Result from SmartPLS4 Tool Analysis*

	DE		PE		TN
DE1	1.338	**PE1**	1.710	**TN1**	1.525
DE2	1.564	**PE2**	2.275	**TN2**	1.604
DE3	1.382	**PE3**	2.128	**TN3**	1.522
DE4	1.435	**PE4**	1.829	**TN4**	1.767
DE5	1.335	**PE5**	1.698	**TN5**	1.781

	SM		TA		OM
SM1	1.706	**TA1**	1.425	**OM1**	1.923
SM2	1.821	**TA2**	1.494	**OM2**	2.379
SM3	1.340	**TA3**	1.307	**OM3**	2.360
SM4	1.774	**TA5**	1.372	**OM4**	3.110
SM5	1.970			**OM5**	3.114

As can be observed from the table, the VIF values of all the constructs are considerably below the specified limit of 5 (Ringle et. al., 2015). Thus, it can be concluded that multicollinearity does not exist in the proposed model.

6.1.3 INTER-CONSTRUCT CORRELATION

Inter-construct correlation represents the estimated correlation between constructs. The inter-construct correlation matrix for the proposed model is shown in Table VIII.

Table VIII *Inter-Construct Correlation Test Result from SmartPLS4 Tool*

	DE	OM	PE	SM	TA	TN
DE	**1.000**					
OM	0.702	**1.000**				
PE	0.635	0.787	**1.000**			
SM	0.516	0.702	0.534	**1.000**		
TA	0.604	0.714	0.722	0.557	**1.000**	
TN	0.623	0.762	0.681	0.562	0.650	**1.000**

As can be seen from the table, values of inter-construct correlations are greater than 0.5. Thus, it can be concluded that there is a valid and meaningful structural model.

6.2 Structural Equation Modelling (SEM)

Structural equation model derived from Smart PLS 4 with path coefficients is shown in Figure 3.

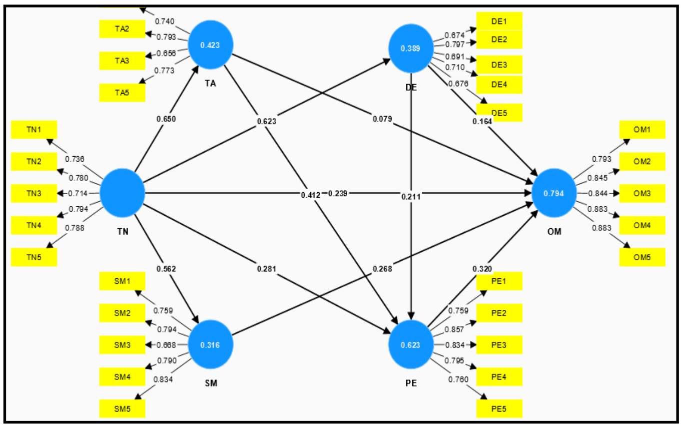

Figure 3 *Structural Equation Modelling results from Smart PLS4*

6.2.1 Coefficient of Determination (R^2)

The R^2 Value of 0.794 for the dependent variable "Leadership in Semiconductor Industry" shows that 79.4% of the latent variable can be explained by the contributing factors included as part of the SEM analysis. This value of R^2 = 0.794, is comparatively high for the PLS regression model as per Henseler & Fassott (2010).

6.2.2 Assessment Of Hypothesis and Path Coefficients

T-test was used to determine if a significant relationship exists amongst the constructs in the model (Hair et. al.,2012). The structural equation model brought out significance of each of the determinants defining their respective constructs.

Table IX :Significance test results from SmartPLS tool for Direct relationships

	Original sample (Beta)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Significant?
PE -> OM	**0.320**	0.305	0.057	**5.578**	**0.000**	**Yes**
SM -> OM	**0.268**	0.283	0.089	**2.996**	**0.003**	**Yes**
DE -> OM	**0.164**	0.159	0.059	**2.758**	**0.006**	**Yes**
TA -> OM	**0.079**	0.066	0.052	**1.516**	**0.130**	**No**
TN -> OM	**0.239**	0.247	0.081	**2.941**	**0.003**	**Yes**

The structural equation model brought out significance of each of the determinants defining their respective constructs

6.2.2.1 *Impact of Production Excellence (PE)*

Table X shows how effectively are each of the five sub-variables impacting Production Excellence (PE) as a holistic view.

Table X :Hypothesis tested for determinants of Production Excellence

Research question: Does Production Excellence impact the Leadership of company in Semiconductor industry? **Hypothesis 1 (H1):** Production excellence significantly impacts the Leadership in Semiconductor Industry through Production Quality, Reliability, Packaging Technology, Smart Manufacturing and Production Cost						
Determinants			**Loading**	**T statistics (|O/STDEV|)**	**P values**	**Inference**
H1a	**Production Quality**	Application of Artificial Intelligence (AI) in existing Product test infrastructure can solve Silicon product quality gaps	**0.759**	17.650	0.000	**Moderate**
H1b	**Product Reliability**	Reliability aspect of semiconductor product need to be considered right from the start of design phase instead of an afterthought	**0.857**	23.273	0.000	**Strong**
H1c	**Silicon Packaging Technology**	Silicon packaging technology plays a crucial role in overall product competitiveness in semiconductor industry	**0.834**	22.769	0.000	**Strong**
H1d	**Smart Manufacturing**	Real time production data analysis and decision making can be greatly enhanced by Application of Predictive Analytics	**0.795**	21.419	0.000	**Moderate**
H1e	**Production Cost**	Higher process complexity and capital investment have a compounding effect on production issues and production costs	**0.760**	17.463	0.000	**Moderate**

(H1) Hypothesis 1: Production Excellence (PE) significantly impacts the Leadership in Semiconductor Industry through Product Quality, Reliability, Packaging Technology, Smart Manufacturing and Production Cost measures.

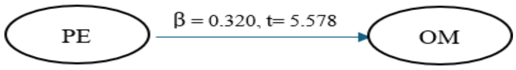

Figure 4 *Influence of Production Excellence on Leadership in Semiconductor Industry*

A significant relationship is found to exist between Production Excellence and Leadership in Semiconductor Industry, based on t-value of 5.578 (i.e. $t > 2.59$) and $\beta = 0.320$ indicates a positive relationship between them. Therefore, the direct impact hypothesis (H1) is accepted at significance level of 1% based on t-value >2.59 and it can be inferred that Production excellence (PE) directly impacts the Leadership position in Semiconductor industry.

6.2.2.2 Impact of Sustainable Manufacturing (SM)

Table XI shows how effectively each of the five sub-variables impact Sustainable Manufacturing(SM) as a holistic view.

Table XI : Hypothesis tested for determinants of Sustainable Manufacturing

Research question: Does Sustainable Manufacturing impact the Leadership of company in Semiconductor industry?

Hypothesis 2 (H2): Sustainable Manufacturing significantly impacts the Leadership in Semiconductor Industry through adaption of eco-friendly material, Industry associations, Digital Transformation, Energy efficient process and Ethical Sourcing

Determinants			Loading	T statistics (|O/STDEV|)	P values	P values
H2a	Eco-friendly material	R&D investment in finding eco-friendly alternative chemical substances for semiconductor manufacturing gains competitive advantage	0.759	18.565	0.000	Moderate
H2b	Industry Associations	Industry associations play a crucial role in driving sustainable practices for the Semiconductor industry	0.794	23.120	0.000	Moderate
H2c	Digital Transformation	Productivity and sustainability goals can be significantly improved with application of Artificial Intelligence (AI)	0.668	11.699	0.000	Moderate
H2d	Energy Efficient Processes	Governments play a crucial role in driving energy efficient processes in collaboration with industry stakeholders	0.790	22.936	0.000	Moderate
H2e	Ethical Sourcing	Ethical sourcing practices help drive sustainability and compliance goals for Semiconductor industry	0.834	29.186	0.000	Strong

(H2) Hypothesis 2: Sustainable Manufacturing significantly impacts the Leadership in Semiconductor Industry through adaption of eco-friendly material, Industry associations, Digital Transformation, Energy efficient process and Ethical Sourcing

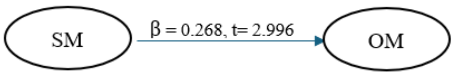

Figure 5 *Influence of Sustainable Manufacturing on Leadership in Semiconductor Industry*

A significant relationship exists between Sustainable Manufacturing and Leadership in Semiconductor Industry based on t-value of 2.996 (i.e. $t > 2.59$) and $\beta = 0.268$ indicates a positive relationship between them. Therefore, the direct impact hypothesis (H2) is accepted at significance level of 1% based on t-value >2.59 and it can be inferred that Sustainable Manufacturing (SM) directly impacts the Leadership position in Semiconductor industry.

6.2.2.3 Impact of Digital Economy (DE)

Table XII shows how effectively each of the five sub-variables impacting Digital Economy (DE) as a holistic view.

(H3) Hypothesis 3: Digital Economy significantly impacts the Leadership in Semiconductor Industry through Data Security, IP, Product lifecycle, Global Workforce and Ethical Challenges

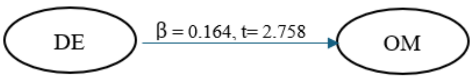

Figure 6 *Influence of Digital Economy*

A significant relationship exists between Digital Economy and Leadership in Semiconductor Industry based on t-value of 2.758 (i.e. $t > 2.59$) and $\beta = 0.164$ infers that the relationship is a positive relationship. Therefore, the direct impact hypothesis (H3) is accepted at significance level of 1% based on t-value >2.59 and it can be inferred that Digital Economy (DE) directly impacts the Leadership position in Semiconductor industry.

Table XII *Hypothesis tested for determinants of Digital Economy*

Research question: Does Digital Economy impact the Leadership of company in Semiconductor industry?						
Hypothesis 3 (H3): Digital Economy significantly impacts the Leadership in Semiconductor Industry through Data Security, IP, Product lifecycle, Global Workforce and Ethical Challenges						
Determinants			**Loading**	**T statistics (|O/STDEV|)**	**P values**	**Inference**
H3a	**Data Security**	Consumers trust open development platforms from bigger players for sharing data than small scale platforms	**0.674**	11.793	0.000	**Moderate**
H3b	**Intellectual Property**	Protection of Intellectual Property rights is the backbone of semiconductor companies to maintain global competitiveness	**0.797**	27.619	0.000	**Moderate**
H3c	**Product Lifecycle**	Regularly introducing new products in the market is the right strategy for grabbing opportunities in turbulent market	**0.691**	14.366	0.000	**Moderate**
H3d	**Global Workforce**	Temporary Migration programs and Contract worker policies play a crucial role in access to talent pool since Semiconductor expertise is distributed globally	**0.710**	15.135	0.000	**Moderate**
H3e	**Ethical Challenges**	Ethical compliance is the biggest challenge for semiconductor products as more and more devices and applications collect personal and industrial data	**0.676**	13.189	0.000	**Moderate**

(H4) Hypothesis 4 : Digital Economy (DE) is mediated by Production Excellence (PE) for significant impact to the Leadership in Semiconductor Industry

Figure 7 *Influence of Digital Economy on Leadership in Semiconductor Industry through mediation of Production Excellence*

Specific Indirect effect Output	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
DE -> PE -> OM	0.068	0.066	0.033	2.064	0.039

The Hypothesis 4 (H4) is thus accepted at 5% level of significance as t-value = 2.064 (t >1.96). Thus, it can be determined that Digital Economy (DE) is mediated by Production Excellence (PE) for having a significant impact on the Leadership position in semiconductor industry.

6.2.2.4 *Impact of Technical adeptness (TA)*

Table XIII shows how effectively each of the sub-variables impact Technical Adeptness (TA) as a holistic view. During the analysis, TA4 was found to be non-significant and hence not considered in the analysis.

(H5) Hypothesis 5 : Technical Adeptness (TA) significantly impacts the Leadership in Semiconductor Industry through Product Architecture, Innovation, Collaborative Practices and Ethical Design practices.

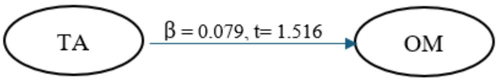

Figure 8 *Influence of Technical Adeptness on Leadership in Semiconductor Industry*

The direct impact inference indicates a non-significant relationship between Technical Adeptness (TA) and Leadership in Semiconductor Industry, with a t-value of 1.516 (i.e. t < 1.65). Therefore, the direct impact hypothesis (H5) is rejected.

(H6) Hypothesis 6: Technical Adeptness (TA) is mediated by Production Excellence (PE) for significant impact to the Leadership in Semiconductor Industry.

Figure 9 *Influence of Technical Adeptness on Leadership in Semiconductor Industry through mediation of Production excellence.*

Specific Indirect effect Output	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
TA -> PE -> OM	0.132	0.121	0.039	3.423	0.001

The Hypothesis 6 (H6) is thus accepted at 1% level of significance as t-value = 3.423 (t >2.59). Thus, it can be determined that Technical Adeptness (TA) is mediated by Production Excellence (PE) for having a significant impact on the Leadership position in semiconductor industry.

Table XIII *Hypothesis tested for Determinants of Technical Adeptness*

Research question: Does Technical adeptness impact the Leadership of company in Semiconductor industry?

Hypothesis 5 (H5): Technical Adeptness significantly impacts the Leadership in Semiconductor Industry through Product architecture, Collaborative Practices, Innovation and Ethical Design

No.	Determinant hypothesis		Loading	T statistics (|O/STDEV|)	P values	Inference
H5a	**Product Architecture**	Existing Silicon architecture has reached its limits and needs a fundamental change with alternate architectural approach for future products to succeed	**0.740**	14.144	0.000	**Moderate**
H5b	**Collaborative practices**	Engagement in Industry collaboration on Open Innovation can help Semiconductor company gain competitive advantage	**0.793**	20.060	0.000	**Moderate**
H5c	**Innovation**	A Semiconductor company needs to invest equally in shallow technologies as well as deep technologies to gain a competitive edge	**0.656**	10.640	0.000	**Moderate**
H5d	**Ethical Design**	Designers of semiconductor products need to abide by ethical design goals while designing the products	**0.773**	21.498	0.000	**Moderate**

6.2.2.5 *IMPACT OF TECHNO-NATIONALISM (TN)*

Table XIV shows how effectively are each of the five sub-variables impacting Techno-nationalism as a holistic view.

(H7) Hypothesis 7: Techno-nationalism significantly impacts the Leadership in Semiconductor Industry through Federal Investments, Value Chain, Geographical Shifts, Geo-political tensions, and public procurement policy.

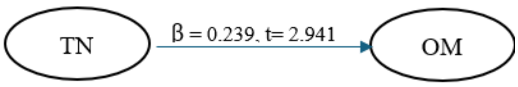

Figure 10 *Influence of Techno-Nationalism on Leadership in Semiconductor Industry*

A significant relationship between Techno-nationalism (TN) and Leadership in Semiconductor Industry was established with a t-value of 2.941 (i.e. t > 2.59) and β = 0.239 indicates that the relationship is a positive relationship. Therefore, the direct impact hypothesis (H7) is accepted at significance level of 1% based on t-value >2.59

(H8) Hypothesis 8: Techno-nationalism (TN) is mediated by Production Excellence (PE) for significant impact to the Leadership in Semiconductor Industry

Figure 11 Influence of Techno-Nationalism on Leadership in Semiconductor Industry through Mediation of Production Excellence

Specific Indirect effect Output	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
TN -> PE -> OM	0.090	0.086	0.034	2.616	0.009

The Hypothesis 8 (H8) is thus accepted at 1% level of significance as t-value = 2.616 (t >2.59). Thus, it can be determined that Techno-nationalism (TN) is mediated by Production Excellence (PE) for having a significant impact on the Leadership position in semiconductor industry.

Table XIV *Hypothesis tested for Determinants of Techno-Nationalism*

Research question: Does Techno-Nationalism impact the Leadership of company in Semiconductor industry?

Hypothesis 7 (H7): Techno-nationalism significantly impacts the Leadership in Semiconductor Industry through Federal Investments, Value Chain, Geographical Shifts, Geo-political tensions, and public procurement policy.

Determinants			Loading	T statistics (|O/STDEV|)	P values	Inference
H7a	**Federal investments**	Federal investments and incentives boost the growth of semiconductor indust1ry	**0.736**	13.603	0.000	**Moderate**
H7b	**Value Chain**	Semiconductor value chains are widely distributed across geographies; hence, companies actively manage and invest in their value chain	**0.780**	19.669	0.000	**Moderate**
H7c	**Geographics Shifts**	Semiconductor companies face high strategic vulnerability as Manufacturing is majorly concentrated in Eastern World and Design/Technology concentrated in Western World	**0.714**	15.368	0.000	**Moderate**
H7d	**Geo-Political Tensions**	Increasing Geo-political tensions and national security concerns drive Governments to invest in semiconductor industry for their own national interest	**0.794**	18.862	0.000	**Moderate**
H7e	**Public Procurement Policy**	Public procurement policies in favor of local sourcing can help drive development of semiconductor Industry in a country	**0.788**	21.787	0.000	**Moderate**

(H9) Hypothesis 9: Techno-nationalism (TN) is mediated by Sustainable Manufacturing (SM) for significant impact to the Leadership in Semiconductor Industry

Figure 12 *Influence of Techno-nationalism on Leadership in Semiconductor Industry through mediation of Sustainalbe Manufacuring*

Specific Indirect effect Output	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
TN -> SM -> OM	0.151	0.163	0.069	2.169	0.030

The Hypothesis 9 (H9) is thus accepted at 5% level of significance as t-value = 2.169 (t >1.97). Thus, it can be determined that Techno-nationalism (TN) is mediated by Sustainable Manufacturing (SM) for having a significant impact on the Leadership position in semiconductor industry.

(H10) Hypothesis 10: Techno-nationalism (TN) is mediated by Digital Economy (DE) for significant impact to the Leadership in Semiconductor Industry

Figure 13 *Influence of Techno-nationalism on Leadership in Semiconductor Industry through Mediation of Digital Economy*

Specific Indirect effect Output	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
TN -> DE -> OM	0.102	0.100	0.043	2.399	0.016

The Hypothesis 10 (H10) is thus accepted at 5% level of significance as t-value = 2.399 (t >1.97). Thus, it can be determined that Techno-nationalism (TN) is mediated by Digital Economy (DE) for having a significant impact on the Leadership position in semiconductor industry.

(H11) Hypothesis 11: Techno-nationalism (TN) is mediated by Technical Adeptness (TA) for significant impact to the Leadership in Semiconductor Industry

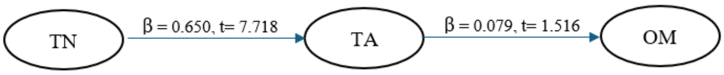

Figure 14 *Influence of Techno-nationalism on Leadership in Semiconductor Industry through mediation of Technical Adeptness*

Specific Indirect effect Output	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
TN -> TA -> OM	0.051	0.043	0.035	1.482	0.138

The Hypothesis 11 (H11) is rejected based on t-value 1.482 ($t < 1.59$). Thus, it can be determined that Techno-nationalism (TN) when mediated by Technical Adeptness (TA) does not have a significant impact on the Leadership position in semiconductor industry

6.2.2.6 Outcome Measure (OM) for Leadership in Semiconductor Industry

Five benefits determining the dependent variable as shown in Table XV .

Table XV *Hypotheses Tested for the Determinants of the Dependent Variable*

Determinants			Loading	T statistics |O/STDEV|	P values	Inference	
Hom1	**Differentiated Products (OM1)**	Embracing Technology focused strategies help drive differentiated products delivering superior customer experience	**0.793**	18.746	0.000	**Moderate**	Technology Adeptness significantly impacts the Differentiated Products
Hom2	**Sustainable Competitive Advantage (OM2)**	Focus on Production excellence (Quality, reliability, Cost, Technology) provides sustainable competitive advantage	**0.845**	20.925	0.000	**Strong**	Production Excellence significantly impacts Sustainable competitive advantage
Hom3	**Resilient Supply Chain (OM3)**	Government Support and policy effectiveness help build a resilient supply chain	**0.844**	27.158	0.000	**Strong**	Techno-nationalism significantly impacts the resilient supply chain
Hom4	**Brand Value (OM4)**	Building strong foundation for digital economy (IP Protection, Data security, Privacy, Ethics) increase the Brand Value	**0.883**	34.786	0.000	**Strong**	Driving on Digital Economy significantly impacts Brand Value
Hom5	**Circular Economy (OM5)**	Driving Sustainable Manufacturing reflects company's commitment towards Circular Economy and sustainability goals	**0.883**	38.823	0.000	**Strong**	Sustainable manufacturing significantly impacts Circular economy

The benefits were used as measures of the research outcome wherein four benefits (OM2, OM3, OM4, OM5) determining the Leadership position in Semiconductor Industry were found to be having a “Strong” influence and one of the benefits (OM1) showed a “Moderate” influence.

7. Conclusion

This study presented the outcome from data analysis through Structural Equal Model (SEM) using Smart PLS 4. Structural Model was tested for reliability and validity and concluded that there is a valid and meaningful structural model. R^2 Value of 0.794 for the dependent variable “Leadership in Semiconductor Industry” showed that 79.4% of the latent variable can be explained by the contributing factors included as part of the SEM analysis.

Table XVI *Summary of Hypothesis –Variables with Significant Direct Influence*

Variable	Beta value	T statistics	P values
Production Excellence (PE)	$\beta_{PE-OM} = \mathbf{0.320}$	**5.578**	**0.000**
Sustainable Mfg. (SM)	$\beta_{SM-OM} = \mathbf{0.268}$	**2.996**	**0.003**
Digital Economy (DE)	$\beta_{DE-OM} = \mathbf{0.164}$	**2.758**	**0.006**
Techno-Nationalism (TN)	$\beta_{TN-OM} = \mathbf{0.239}$	**2.941**	**0.003**

Technical Adeptness (TA), was statistically observed to have an insignificant influence on the Leadership in Semiconductor industry. Production Excellence (PE) emerged as variable having strongest direct influence on Leadership in semiconductor industry, followed by Sustainable Manufacturing (SM), Techno-nationalism (TN) and Digital Economy (DE) in that order.

Table XVII *Summary of Hypothesis –Hypotheses with Significant Indirect Influence*

Independent Variable	Mediation Through	Beta value	T stat	P values
Digital Economy (DE)	**Production Excellence (PE)**	$\beta_{DE-PE-OM} = \mathbf{0.068}$	**2.064**	**0.039**
Technical Adeptness (TA)	**Production Excellence (PE)**	$\beta_{TA-PE-OM} = \mathbf{0.132}$	**3.423**	**0.001**
Techno-nationalism (TN)	**Production Excellence (PE)**	$\beta_{TN-PE-OM} = \mathbf{0.090}$	**2.616**	**0.009**
Techno-nationalism (TN)	**Digital Economy (DE)**	$\beta_{TN-DE-OM} = \mathbf{0.102}$	**2.399**	**0.016**
Techno-nationalism (TN)	**Sustainable Mfg. (SM)**	$\beta_{TN-SM-OM} = \mathbf{0.151}$	**2.169**	**0.030**

Digital Economy (DE) had a significant impact on Leadership in Semiconductor industry when mediated by Production excellence. Technical Adeptness (TA) has a significant impact on Leadership in Semiconductor industry when mediated by Production Excellence (PE). Techno-nationalism (TN) has a significant impact on Leadership in Semiconductor industry when mediated by Production excellence (PE). Techno-nationalism (TN) has a significant impact on Leadership in Semiconductor industry when mediated by Digital Economy (DE). Techno-nationalism (TN) has a significant impact on Leadership in

Semiconductor industry when mediated by Sustainable Manufacturing (SM). Techno-nationalism (TN) did not show a significant impact on Leadership in Semiconductor industry when mediated by Technical Adeptness (TA).

Thus, four out of five independent variables having a direct relationship were empirically proven to have significant influence on the dependent variable. Five out of six indirect relationship tested were empirically proven to have significant influence on the dependent variable when mediated by another independent variable.

The research will significantly impact academia and industry, contributing through analysis and proposed framework. The case study shall result in enrichment of research knowledge and practice for the students through proposed theoretical model. This case study research is valuable for semiconductor companies, similar technology companies operating in global environment, service providers, Industry bodies and government policymakers, as it provides detailed insights and valuable actionable strategies that can be integrated into their respective organizations. The managers and leadership of the company needs to understand and internalize the impact of external environment on the internal operations and development.

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