Constructing a Sustainable Innovation System for Green Transformation: A Synergistic Framework of Resource Orchestration and Organizational Resilience

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***Abstract*—Green transformation has become a key pathway for manufacturing firms to achieve sustainable development. Drawing on resource orchestration theory and dynamic capabilities theory, this study develops a research model linking resource orchestration, substantive green innovation, organizational resilience, and firm performance. A survey-based quantitative design was adopted, and questionnaire data from senior and middle managers of Chinese manufacturing listed firms were matched with publicly available green patent and financial indicators. Based on 312 firm-level observations, partial least squares structural equation modeling (PLS-SEM) was used to test the proposed relationships. The results suggest that resource orchestration is positively associated with substantive green innovation, which is further associated with environmental and financial performance. Substantive green innovation also serves as a mediating mechanism between resource orchestration and firm performance, while organizational resilience strengthens the relationship between resource orchestration and substantive green innovation. The findings provide empirical evidence for understanding how dynamic resource management and organizational resilience support sustainable innovation and green transformation in manufacturing firms.**

Keywords—green transformation, sustainable innovation, resource orchestration, organizational resilience, substantive green innovation, PLS-SEM

I. INTRODUCTION

As the crisis of environmental degradation continues to grow in scale worldwide, and with the advent of carbon-neutrality goals, green transformation has become a compliance-driven penalty, shifting to become a fundamental element of strategy to redefine competitive advantage [1]. On this basis, sustainable innovation is commonly perceived as the most important route that companies can take to make a positive contribution to both economic and environmental gains. In reality, however, many firms get caught up in the web of what could be considered as a form of a trap known as "strategic greenwashing," instead of doing what is called "substantive green innovation," to produce significant environmental change [2]. The issue of how businesses can address the double limitation of resources and capabilities to develop a sustainable innovation system based on green transformation has thus become an acute concern to both scholars and practitioners.

The available literature on the antecedents of green innov ation has mainly paid attention to the external institutional pr essures, including environmental regulations and stakeholder requirements [3], and the internal executive characteristics, i ncluding managerial environmental cognition [4]. In terms of a resource approach, initial works were mainly based on the resource-based approach (RBV), which asserts that static res ources ownership is where competitive advantage originates [5]. However, today, in the context of increasing technologic al iteration and increased environmental uncertainty, the sim ple fact of resource ownership is not enough to ensure the su ccess of innovation. According to the resource orchestration t heory (ROT) proposed by Sirmon et al., it is the dynamic nat ure of resources management, i.e. structuring, bundling, and l everaging, that serves as the true value creator [6]. Unfortuna tely, there are very limited numbers of studies that have form ally incorporated the concept of resource orchestration theory into the green transformation scenario to explore its micro-le vel mechanisms causing the significant green innovation.

Furthermore, in the course of trying to achieve green transformation, companies often have to deal with significant research and development expenses, technology failure hazards, and unpredictable market demand. Why is it that during a very turbulent shift phase, firms with similar levels of resource orchestration demonstrate significant differences in green innovation output? Dynamic capabilities theory development provides a new perspective on how to answer the question [7]. Organizational resilience is a sophisticated dynamic capability which indicates the ability of a company to withstand shocks, change and reach transformational upgrading despite adversity [8]. Its inclusion as a boundary condition within the resource orchestration framework allows making clear what kind of contingent mechanisms are behind green innovation in turbulent conditions.

With these gaps in mind, this study will address the following central questions: in environmental uncertainty, how can a company use the concept of resource orchestration to develop meaningful green innovation and improve the dual performance, and what kind of synergistic effect may organizational resilience have to play in the process?This

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paper has made three small contributions. First, it has used resource orchestration theory in the context of green transformation and has looked at how resource structuring, bundling and leveraging relate to substantive green innovation. Second, it has presented organizational resilience as a contingency variable which can influence the effectiveness of resource orchestration during environmental uncertainty. Third, with the help of perceptual survey measures and certain secondary indicators, the study has offered empirical information about the interconnection between resource management, green innovation, and performance of an organization. Still, since the research design is cross-sectional, the findings must be regarded as correlational and not causal.

The rest of this paper will be structured in the following manner. Section 2 discusses the relevant literature and generates the theoretical hypotheses. Section 3 explains the research methodology and how the data was collected. Section 4 gives the empirical analysis of the PLS-SEM. Section 5 offers a detailed analysis, comparison, and attribution of the results. Lastly, Section 6 summarizes the study and provides suggestions on the way forward regarding future research.

II. Literature Review and Hypotheses

A. Theoretical Foundations and Conceptual Definitions

The concept of resource orchestration theory (ROT). According to the conventional resource-based view (RBV), valuable, rare, inimitable and non-substitutable resources are the source of a firm ' s competitive advantage [5]. Nevertheless, Sirmon et al. claim that simply having resources does not necessarily produce a competitive advantage but rather dynamic orchestration implemented by managers is important [6]. A resource orchestration consists of three main steps which include resource structuring (getting, building, and disposing of resources to create a resource portfolio), resource bundling (combining resources to create unique capabilities), and resource leveraging (using capabilities to take advantage of market opportunities). In the green transformation environment, resource orchestration is a dynamic organization of environmental technologies, green capital, and human talent of a firm.

Organizational resilience (OR) Organizational resilience has its roots in ecology and psychology and was later applied to the field of strategic management. According to Lengnick-Hall et al., it can be described as a power of a company to restore its initial position during the process of coping with the disruptive events, as well as to gain counter-cyclical development by means of adaptation and transformation [8]. The three dimensions that are identified in this paper include anticipation and defense capacity, adaptation capacity, and transformation capacity.

Substantive green innovation (SGI) is distinguished by the fact that it is not a response to external pressures but an effort made by companies to achieve a fundamental change in technology and systemic innovation during the product life cycle, manufacturing processes or business models to reduce their negative influence on the environment [2].

B. Resource Orchestration and Substantive Green Innovation

Green transformation as an organizational process entails companies to overcome their current technological paths and mental inertia. Initially, during the phase of resource structuring, firms gain access to advanced green technologies and environmental capital using external search, and dispose of intensive polluters and outdated capacities, thus forming the material basis and knowledge base of green innovation [9]. Subsequently, during the resource bundling stage, firms tightly combine heterogeneous green resources with current production processes into green dynamic capabilities that are hard to replicate by competitors [10]. Lastly, during the resource leveraging stage, firms activate the green capabilities that they have developed in order to focus on particular new-product development or process improvement initiatives, which exactly match the demand of the green market and hence deliver significant green innovation outputs [11]. Consequently, the organized functioning of resource orchestration is the underlying cause of eliminating the high-risk and long-cycle character of green innovation. Thus, the next hypothesis can be formulated:

H1. Resource orchestration capability positively influences a firm's substantive green innovation

C. Substantive Green Innovation and Firm Performance

Substantive green innovation has a positive effect on the performance of the company both environmentally and financially. Regarding environmental performance (EP), deep green-process innovation may minimize the emission of pollutants at their source and increase the efficiency of resources use, thus, greatly improving the ecological footprint of a firm [12]. Concerning the financial performance (FP), despite the fact that green innovation will need a high level of capital investment within a short period of time, over the long-term substantive green innovation helps companies to earn green premiums, save on environmental compliance expenses, and develop a green image, which all lead to financial benefits in the form of sustainable returns [13]. Therefore, the hypotheses presented are:

H2a. Substantive green innovation positively influences a firm's environmental performance.

H2b. Substantive green innovation positively influences a firm's financial performance.

D. The Mediating Role of Substantive Green Innovation

Resource orchestration as an internal management procedure cannot be directly transformed to market value or ecological benefits. Based on the resource-capability-performance logic chain, resource orchestration needs to be directed into certain strategic actions (e.g. innovation) to achieve value creation [6]. The internal potential energy that is built up by the firms during the process of structuring, bundling and leveraging the resources could eventually enhance the environmental performance as well as produce financial gains provided that this potential energy is translated to tangible green innovation outcomes such as introducing green new products or using clean production technologies; this materialisation becomes especially important when the firm has to adjust and reshape its resources due to turbulence and crisis situations [14]. Therefore, the next hypothesis is stated:

Substantive green innovation is a mediator in the relationship between resource orchestrating capability and the performance of the company (environmental and financial performance).

E. The Moderating Role of Organizational Resilience

During an extremely uncertain and volatile transitional stage, the effectiveness of resource orchestration is frequently destabilized by external shocks (including sudden policy changes and technological disruption). Organizational resilience can be considered a boundary condition because it is an advanced dynamic capability that helps deal with crisis and change - a condition that makes resource orchestration able to deliver its impact [8]. Firms that are very resilient have an astute sense of anticipation and defense, which allows them to perceive the changes in environmental regulation early on and save space in their resource orchestration buffer; their high adaptation capacity allows them to quickly reorganize their organization structures when they bundle resources to fit green innovation needs; and their transformation capacity helps them speed up the shift in resource leverage towards a new business model [15]. On the other hand, low-resilient firms are vulnerable to strategic rigidity in the face of shocks, which results in structural breaks in the resource orchestration process, which cannot be successfully transformed into meaningful green innovation. Consequently, there is the proposed hypothesis:

H4. There is a positive moderation of organizational resilience on the association between resource orchestration capability and substantive green innovation: the higher the organizational resilience, the greater the facilitation of resource orchestration in substantive green innovation(Fig.1).

Fig. 1 Conceptual Model and Research Hypotheses

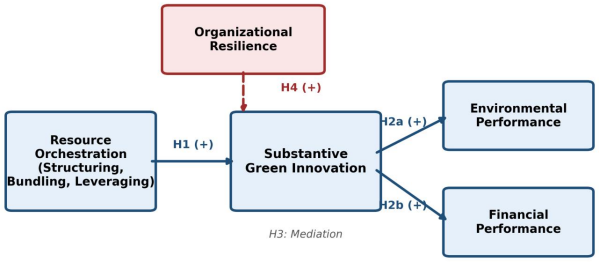

Fig. 1. Conceptual Model and Research Hypotheses.

III. Methodology

A. Research Strategy and Sampling

The research is based on the Chinese manufacturing listed companies since these companies are vulnerable to an increased level of environmental regulations and are put under significant pressure to engage in the green transformation. The original sampling frame was made up of listed manufacturing companies that can be found in public corporate databases. All the companies that had no major financial data, unusual operating condition or incomplete questionnaire replies were not included. The survey addressed senior and middle managers, who were supposed to have the knowledge of the resource allocation, innovation activities, and environmental management practices, which includes general managers, technology managers, strategy managers, and environmental management staff.

It was disseminated via professional networks, email contact, and subsequent communication. All the participants of the study were given informed consent and were told that their contribution was voluntary and anonymous. To minimize the problem of single informant bias, the respondents were instructed to respond in case they had adequate information on their companies green innovation and resource management policies. The incomplete answers and those with clear straight-line answering patterns were removed leaving 312 valid firm-level matched observations to be analyzed. Survey data was subsequently matched with secondary firm-level data such as green patents indicators and measures of financial performance. Despite the fact that the end sample represents the firms with diverse ownership types and firm ages, it must be considered a usable empirical sample but not a statistically representative sample of all Chinese manufacturing companies.

The overall research framework and analytical procedure are summarized in Fig. 2.

Fig. 2 Research Framework and Analytical Procedure

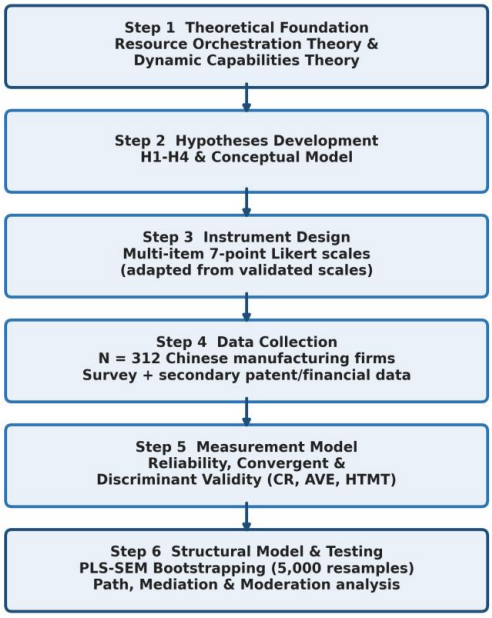

Fig. 2. Research Framework and Analytical Procedure.

B. Data Sources and Matching Procedure

The research has employed two kinds of data. Perceptual variables such as resource orchestration, organizational resilience and aspects of green innovation and environmental performance were assessed using questionnaire responses First, objective or semi-objective data, like green patent registrations and financial performance data, were gathered in publicly accessible databases and company disclosures Second, firm names, stock codes and reporting years were matched to survey responses with secondary data. If the survey data and archival records were inconsistent, a manual check was made of the observation and it was discarded when such inconsistency could not be addressed.

The information on the green patents was taken as a side-effect indicator that would confirm the substantive green innovation, not as the single measure of innovation. Financial indicators were applied to lower the use of self-reported performance evaluations. This matching process was selected because it would reduce, but not entirely remove, the possible common method bias effect.

C. Measures

The latent variables were all measured using multi-item s cales that were based on previous studies and modified to sui t the green transformation context. It was assessed on a seven -point Likert scale of 1 = strongly disagree to 7 = strongly ag ree. The concept of resource orchestration was evaluated in t erms of three dimensions which are resource structuring, reso urce bundling, and resource leveraging. Anticipation, adaptat ion, and transformation capacities were measures of organiza tional resilience. Core green technology improvement, clean production process innovation, environmental product design, and life-cycle-oriented innovation activities were used to me asure substantive green innovation. Perceived improvements in pollution reduction, resource utilization, energy saving, an d recycling were used as the measures of environmental perf ormance. Relative improvements in profitability, market shar e, and growth compared with the main competitors were use d as a measure of financial performance.

As a solution to enhance the transparency of measuremen ts, the list of all the adjusted items must be provided in the fo rm of an appendix or a supplementary table. The formulation of the items was examined to see that it is consistent with th e green transformation background. When feasible, perceptu al innovation measures were matched against green patent da ta and perceptual financial performance measures were contr asted against available financial indicators. Since there are sti ll some variables based on the perceptions of managers, the p otential measurement bias can never be entirely eliminated.

D. Common Method Bias

A number of procedural and statistical treatments were applied to alleviate the risk of common method bias. Procedurally, the questionnaire was based on anonymity and it was indicated that there are no correct or incorrect answers. The measurement items related to independent variables, mediating variables, moderating variables and dependent variables were arranged separately in order to minimize the tendency of respondents to make inferences about the research hypotheses. Also, some of the performance and innovation data were cross-validated with secondary data wherever possible.

Harman single-factor test was initially statistically administered as a preliminary diagnostic. The initial unrotated factor accounted for 34.2% of the entire variance, which is less than the 50 percent threshold that is typically applied. Nevertheless, due to the constrained nature of Harman test, its outcome cannot be taken as the final proof of nonexistence of common method bias. Thus, the research considers common method bias as a possible limitation and interprets the empirical findings cautiously.

IV. Results

PLS-SEM was used to test the proposed model because the study focuses on prediction-oriented relationships among multiple latent constructs and includes both mediating and moderating effects [16]. The analysis was conducted using SmartPLS 4.0. The evaluation followed a two-step procedure: first, the reliability and validity of the measurement model were assessed; second, the structural model was examined through path coefficients, bootstrapping results, explanatory power, and collinearity diagnostics. Since the data are cross-sectional, the PLS-SEM results are interpreted as statistical associations rather than causal proof.

A. Measurement Model Assessment

The measurement model was evaluated in terms of internal consistency reliability, convergent validity, and discriminant validity. Cronbach's alpha and composite reliability values were examined for each construct, and values above 0.70 were considered acceptable. Convergent validity was assessed using standardized factor loadings and average variance extracted (AVE). Items with low factor loadings should be removed only when there is both statistical and theoretical justification. Discriminant validity was assessed using the Fornell–Larcker criterion and the heterotrait–monotrait ratio (HTMT).

Table I reports the descriptive statistics and correlations among the main variables. To make the results reproducible, an additional measurement table should report each construct's factor loadings, Cronbach's alpha, composite reliability, AVE, and HTMT values. Without these details, the reliability and validity claims should be interpreted cautiously.

TABLE I. Descriptive Statistics and Correlation Matrix

Variable	Mean	SD	RO	OR	SGI	EP	FP
Resource Orchestration (RO)	4.787	1.034	0.782				
Organizational Resilience (OR)	4.495	1.164	0.105	0.754			
Substantive Green Innovation (SGI)	4.121	0.969	0.524	0.163	0.815		
Environmental Performance (EP)	3.829	0.926	0.297	0.109	0.646	0.796	
Financial Performance (FP)	3.721	0.979	0.214	0.067	0.393	0.317	0.822

[a.] Note: Bold diagonal values are the square roots of the AVE; ** $p < 0.01$, * $p < 0.05$.

With respect to discriminant validity, the square root of the AVE for each latent variable exceeded its correlations with the other variables (the Fornell–Larcker criterion); in addition, all heterotrait–monotrait (HTMT) ratios were below 0.85, further confirming that the model possesses sound discriminant validity.

B. Structural Model and Hypothesis Testing

After the measurement model assessment, the structural model was tested using a bootstrapping procedure with 5,000 resamples. Before interpreting the path coefficients, collinearity was examined using variance inflation factors. The results show that resource orchestration is positively associated with substantive green innovation, supporting H1. Substantive green innovation is positively associated with environmental performance and financial performance, supporting H2a and H2b. These results indicate that firms with stronger resource orchestration capabilities tend to

report higher levels of substantive green innovation, which in turn is associated with better environmental and financial outcomes.

The mediation effect proposed in H3 was examined using bootstrapped indirect effects. The mediating role of substantive green innovation should be supported only if the indirect effect is statistically significant and the confidence interval does not include zero. If the direct effect from resource orchestration to firm performance remains significant after adding substantive green innovation, the mediation should be described as partial mediation rather than full mediation. Therefore, the conclusion regarding mediation should be based on the reported direct, indirect, and total effects.

TABLE II. SUMMARY OF HYPOTHESIS TESTING RESULTS

Hypothesis	Path	Path Coefficient (β)	t-value	p-value	Conclusion
H1	Resource Orchestration → Substantive Green Innovation	0.485	9.42	< 0.001	Supported
H2a	Substantive Green Innovation → Environmental Performance	0.612	12.85	< 0.001	Supported
H2b	Substantive Green Innovation → Financial Performance	0.385	6.74	< 0.001	Supported
H4	Resource Orchestration × Organizational Resilience → SGI	0.215	3.18	< 0.01	Supported

Table II summarizes the results of hypothesis testing. The results show that resource orchestration is positively associated with substantive green innovation, supporting H1. Substantive green innovation is positively associated with environmental performance and financial performance, supporting H2a and H2b. In addition, the interaction term between resource orchestration and organizational resilience has a positive and significant effect on substantive green innovation, supporting H4.

C. *Moderating Effect Analysis*

To test the moderating role of organizational resilience, an interaction term between resource orchestration and organizational resilience was included in the model. The interaction effect was positive and statistically significant, indicating that organizational resilience strengthens the association between resource orchestration and substantive green innovation. To interpret this effect, a simple slope analysis was conducted by comparing the relationship between resource orchestration and substantive green innovation at high and low levels of organizational resilience.

The moderating effect plot provides a visual illustration only and should not be treated as sufficient evidence by itself. Therefore, the simple slope coefficients, standard errors, t-values, and confidence intervals should also be reported. This additional information allows readers to evaluate whether the strengthening effect of organizational resilience is statistically and substantively meaningful(Fig.3).

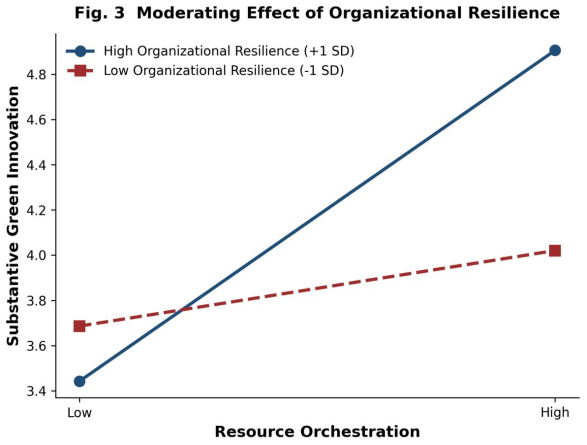

Fig. 3. Moderating Effect of Organizational Resilience.

V. DISCUSSION

A. *The Micro-Mechanism through Which Resource Orchestration Drives Green Innovation*

The empirical results demonstrate that resource orchestration significantly promotes substantive green innovation. This finding engages in dialogue with the traditional resource-based view (RBV) and corroborates the core argument of Sirmon and colleagues [6]: in the highly complex systemic undertaking of green transformation, reliance on static resource endowments alone cannot surmount technological barriers; instead, only through dynamic resource orchestration—structuring, bundling, and leveraging—can idle green resources be converted into substantive innovation outputs.

B. *Deconstructing the Mediating Pathway of Green Innovation*

The study confirms that substantive green innovation is the central bridge linking resource management to dual firm performance. The internal potential energy that firms accumulate through resource orchestration cannot substantively reduce carbon emissions or capture market premiums unless it is channeled into deep technological renewal and process re-engineering—that is, substantive innovation rather than superficial "greenwashing." This provides resource- and capability-based evidence for resolving the longstanding controversy over whether green transformation "pays" [13].

C. *The Synergistic Multiplier Effect of Organizational Resilience*

The most salient theoretical contribution of this study is the confirmation of the positive moderating role of organizational resilience between resource orchestration and green innovation. During a transition period fraught with uncertainty, highly resilient firms can leverage their anticipation and adaptation capacities to withstand the risk of resource dissipation caused by abrupt regulatory shifts, and can leverage their transformation capacity to accelerate the processes of resource bundling and leveraging. This indicates

that the combination of "resource orchestration (hard capability) plus organizational resilience (soft capability)" constitutes the synergistic dual engine driving sustainable innovation in turbulent environments.

VI. Conclusion

A. Core Conclusions

According to the resource orchestration theory and dynamic capabilities theory, this paper investigated how resource orchestration, substantive green innovation, organizational resilience and firm performance were linked in green transformation contexts. The findings indicate three major conclusions. Firstly, it is found that resource orchestration correlates positively with substantive green innovation. Secondly, there seems to be an intermediary role played by substantive green innovation relating resource orchestration to environmental and financial performance. Finally, organization resilience might increase the positive correlation between resource orchestration and substantive green innovation. Such conclusions must be considered in the framework of the cross-sectional research design and the particular sample of listed Chinese manufacturing companies.

B. Theoretical Contributions and Practical Implications

Theoretical contributions. This paper will step out of the excessive dependence of previous studies on external instituti onal pressures regarding antecedents of green innovation, an d reveal the black box of internal dynamic resource manage ment in firms, and in addition, it will extend the theoretical li mits of the sustainable innovation domain by introducing org anizational resilience to the resource orchestration framewor k for the first time.

PRACTICAL APPLICATIONS. In quest of green transformation, managers are required to discard a simple "resource-hoarding" mentality and be able to dynamically manage green resources with them, and simultaneously, they need to raise the level of organizational resilience building to the status of a strategic priority in day-to-day activities, creating agile and resilient flexible organizations that would guarantee efficient execution of green innovation strategies under uncertain conditions.

C. Limitations and Future Research

The study has a number of limitations. The first one is that the cross-sectional framework precludes making strong causal statements. Though the theoretical model suggests the directional relationship, future research ought to utilize longitudinal panels, time-lagged surveys, or quasi-experimental techniques to test causal processes with a greater degree of rigor. Secondly, certain important variables are based on the perception of managers, which might lead to personal bias. The further studies might include more objective measures, including the verified data on emissions, energy usage statistics, spending on the green R&D, and the citation information of patents. Thirdly, the sample is restricted to the Chinese manufacturing listed company, which might limit the applicability of the results to other industries, ownership structure, and nations. Future studies would be able to compare the companies in terms of industries, ownerships, and countries. Fifth, even though this paper employs secondary data in part to verify findings, in future research it should provide a more complete documentation of questionnaire items used, data matching procedures and model diagnostics to improve the level of reproducibility.

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AUTHOR CONTRIBUTIONS

Conceptualization: the author. Methodology: the author. Investigation: the author. Data curation: the author. Formal analysis: the author. Visualization: the author. Writing—original draft: the author. Writing—review and editing: the author. Project administration: the author. The author has read and approved the final manuscript.

COMPETING INTERESTS

The authors declare no competing interests.