Tourism, Takeoff and Growth: A Quantitative Analysis of Macau

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Abstract

This study develops an open-economy Schumpeterian growth model that features endogenous takeoff and a tourism sector. Using this model, we study the role of tourism in shaping the transition of an economy from stagnation to growth. Suppose leisure preference is strong. Then, an expansion in tourism triggers an earlier takeoff and leads to higher transitional growth when tourism reliance is low, but delays takeoff and leads to lower transitional growth when tourism reliance is high. Based on cross-country panel data, we find supportive empirical evidence: the relationship between tourism and economic growth follows an inverted-U pattern. We also calibrate the model to data in Macau, and our quantitative results suggest that the growth-maximizing size of the tourism-related sector is about 60% of GDP.

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"Tourism growth can and should lead to economic prosperity, jobs and resources to fund environmental protection and cultural preservation." UN Tourism (2017)[1]

1 Introduction

Macau, a world-renowned tourism hub and one of the highest per-capita-GDP economies in the world, has experienced rapid GDP growth fueled by a booming tourism sector. However, despite its initial economic success, Macau has struggled to transition beyond tourism-dependent industries and develop high-tech industries, raising concerns about the long-term sustainability of its growth.[2] These contrasting experiences highlight the dual role of tourism in economic development and naturally raise an interesting question: does tourism contribute to the transition of the economy from stagnation to sustained innovation-driven growth? To address this question, we develop a small-open-economy version of the Schumpeterian growth model with a tourism sector and endogenous takeoff. Our key findings are as follows. Suppose leisure preference is weak. Then, an expansion in tourism delays takeoff and reduces the post-takeoff transitional growth rate. Suppose leisure preference is strong. Then, an expansion in tourism has inverted-U effects on both takeoff and transitional growth: the effect is positive when the economy does not heavily rely on tourism, but this effect becomes negative when tourism reliance is high. However, tourism has no effect on the long-run growth rate.

The mechanism underlying the above results is that an expansion in tourism affects the economy by changing firm size. A larger (smaller) firm size makes innovation more (less) profitable, thereby leading to an earlier (a delayed) takeoff from stagnation to innovation-driven growth, as well as higher (lower) post-takeoff transitional growth. In the short run, a higher share of labor allocated to production is associated with a larger firm size. Therefore, the short-run effects of tourism on the timing of takeoff and economic growth depend on how tourism affects the production labor share. While a recent study by Chu *et al.* (2024) shows how tourism affects labor allocation and economic growth in the modern era, it does not consider takeoff "from stagnation to sustained growth"[3], which is the theme of the Nobel Prize in Economics in 2025. Our study complements and extends Chu *et al.* (2024) by introducing endogenous takeoff and examining how tourism shapes the entire phase-transition dynamics of the economy. This broader perspective is crucial for understanding the implications of tourism not only on growth, but also on the transition of the economy from stagnation to growth.

Specifically, since foreign tourists not only consume the domestic final good but also local tourism services, an expansion in tourism affects the production labor share through two opposing channels. On the one hand, it increases demand for the domestic final good, which requires more labor for production and thereby raises the level of employment. We call this positive effect the *employment effect*. On the other hand, it also increases demand for tourism services, which may shift labor away from production toward tourism services. We call this

[1] https://www.unwto.org/archive/global/press-release/2017-08-15/tourism-growth-not-enemy-it-s-how-we-manage-it-counts

[2] Other tourism-dependent economies, such as the Maldives, the Bahamas, and Fiji have also faced challenges similar to those of Macau. In contrast, some economies, such as Spain and Dubai, have benefited from booming tourism and gradually developed high-tech industries, notably in renewable energy and advanced manufacturing.

[3] https://www.nobelprize.org/prizes/economic-sciences/2025/popular-information/

negative effect the *reallocation effect*.[4] Which effect dominates is governed by the strength of leisure preference and the economy's reliance on tourism.

When leisure preference is weak, households already devote most of their available time to work. As a result, an expansion in tourism cannot significantly increase labor supply. Consequently, the employment effect is small and the reallocation effect always dominates. Therefore, under weak leisure preference, an expansion in tourism delays takeoff and reduces the post-takeoff transitional growth rate. When leisure preference is strong, whether the employment or reallocation effect dominates depends on how much the economy relies on tourism. If the economy has low reliance on tourism, job opportunities in the tourism sector are relatively limited, so the reallocation effect is small and the employment effect dominates. However, if the economy is highly reliant on tourism, most of the additional labor flows into the tourism sector, and the reallocation effect dominates. As a result, under strong leisure preference, the effects of tourism expansion on takeoff and transitional growth are non-monotonic and follow an inverted-U pattern. In the long run, however, endogenous market structure governs firm entry, and thus eventually leads to a steady-state level of firm size that is independent of the production labor share. Consequently, tourism has no affect on the long-run growth rate.

In our empirical analysis, we use cross-country panel data with total factor productivity (TFP) and non-tourism GDP as proxies for economic development. Unlike most empirical studies that use GDP or GDP per capita as the proxy, which may mechanically reflect tourism revenues, our proxies capture how tourism affects innovation in non-tourism sectors. Our empirical results imply that the growth-enhancing effect of tourism weakens and eventually becomes negative as tourism reliance increases, consistent with our theoretical predictions. While we rely on cross-country panel data to provide broader empirical implications, our quantitative analysis focuses on Macau to gain deeper insights into how tourism shapes the transition of an economy that is heavily reliant on the tourism sector. In the quantitative analysis, we calibrate our model to Macau's data and quantitatively validate the inverted-U relationship between its tourism reliance and TFP growth. Specifically, the growth-maximizing size of the tourism-related industries is about 60% of GDP. In the data, tourism-related industries (including gaming and non-gambling activities) account for a substantial share of Macau's GDP, reaching about 60%–70% in some peak years and slightly below 60% in recent years.

This study builds on the literature on innovation-driven growth. Romer (1990) develops the first R&D-based growth model that emphasizes the role of variety-expanding innovation in driving economic growth. Early studies by Aghion and Howitt (1992), Grossman and Helpman (1991) and Segerstrom *et al.* (1990) instead highlight the role of quality-improving innovation by developing quality-ladder Schumpeterian growth models. Subsequent studies incorporate both variety expansion and quality improvement into the Schumpeterian growth model by adopting an endogenous market structure.[5] In this vein, Smulders and Van de Klundert (1995) and Peretto (1998, 1999) develop variants with creative accumulation, while Howitt (1999) presents a variant with creative destruction. Recent empirical evidence from Garcia-Macia *et al.* (2019) indicates that innovation is mostly introduced by incumbents rather than entrants, consistent

[4]This reallocation effect marks a key difference between the mechanism of tourism in this study and that of exports in Chu *et al.* (2023), where only the employment effect is present.

[5]Empirical evidence from Laincz and Peretto (2006), Ha and Howitt (2007), Madsen (2008), and Ang and Madsen (2011) supports second-generation Schumpeterian growth models that feature both two dimensions of innovation.

with the notion of creative accumulation. Our study contributes to this literature by developing an open-economy Schumpeterian growth model with a tourism sector and endogenous takeoff to explore how tourism affects the entire dynamics of the economy from stagnation to growth.

This study also relates to the literature on tourism and economic growth. An early study by Sinclair (1998) highlights the dual role of tourism on economic development.[6] Subsequent studies by Pina and Martinez-Garcia (2013) and Liu and Wu (2019) develop capital-based growth models to explore how tourism affects capital accumulation and economic growth. Some recent studies incorporate a tourism sector into R&D-based growth models; see Albaladejo and Martinez-Garcia (2015) and Hamaguchi (2020) for variants based on Romer (1990), and Barrera and Garrido (2018) for a variant based on Aghion and Howitt (1992). These models basically consider only one dimension of innovation, with a focus on growth driven by either variety expansion or quality improvement. Our study is most closely related to Chu *et al.* (2024), who consider two dimensions of innovation and examine the effects of tourism on innovation-driven growth in the modern era. However, they do not consider endogenous takeoff from stagnation to sustained growth. Compared to Chu *et al.* (2024), our study develops a more general model that incorporates endogenous takeoff. In addition, our model considers exports and the social return to variety, which allows us to perform an empirically relevant quantitative analysis for Macau.[7] We contribute to this literature by developing a small-open-economy version of Schumpeterian growth model with a tourism sector and endogenous takeoff. This model allows us to examine how tourism affects both takeoff and post-takeoff economic growth.

Finally, this study draws on insights from the literature on endogenous takeoff from stagnation to sustained economic growth. Galor and Weil (2000) provide the seminal study in unified growth theory (UGT), which emphasizes the endogenous transition of the economy from stagnation to modern economic growth. Subsequent studies explore the effects of various prehistorical and historical factors on this transition and provide empirical support for UGT; see for example, Galor and Moav (2002), Galor and Mountford (2008), Galor *et al.* (2009) and Ashraf and Galor (2011). In addition, Galor (2005, 2011) provides comprehensive reviews of UGT. While UGT provides valuable insights into endogenous takeoff, it typically does not explicitly model the innovation-driven growth process. Building on the Schumpeterian perspective, Peretto (2015) develops a closed-economy R&D-based model that features endogenous takeoff from pre-industrial stagnation to modern innovation-driven growth. A recent study by Chu *et al.* (2023) extends the Peretto model to a small-open-economy version to examine the effects of exports, while their model does not incorporate a tourism sector.[8] Our study contributes to this literature by introducing a tourism sector to a open-economy Schumpeterian growth model with takeoff, which allows us to explore how tourism affects endogenous takeoff and innovation-driven growth.

The rest of this study is organized as follows. Section 2 develops an open-economy version of the Schumpeterian model with a tourism sector and endogenous takeoff. Section 3 shows the theoretical results and supportive empirical evidence. Section 4 performs our quantitative analysis, and Section 5 concludes.

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[6]See also Copeland (1991) and Chao *et al.* (2006) for a discussion on de-industrialization effects of tourism.

[7]Our study also improves upon the empirical analysis in Chu *et al.* (2024) by using a larger sample of cross-country panel data, adopting alternative proxies, and controlling for both country and time fixed effects.

[8]See related studies by Iacopetta and Peretto (2021), Chu *et al.* (2020a), Chu *et al.* (2020b), and Chu *et al.* (2022), which also contribute to this strand of literature.

2 Model

We build on the model in Peretto (2015), which features takeoff from stagnation to innovation-driven growth. Furthermore, Chu *et al.* (2023) introduce international trade to the Peretto model to explore how exports affect endogenous takeoff and economic growth. This study differs from the above studies by incorporating a tourism sector to examine how tourism shapes the entire dynamics of the economy.

While Chu *et al.* (2024) also introduce a tourism sector to the Schumpeterian growth model, they focus only on economic growth in the modern era and do not consider endogenous takeoff. Instead, our model captures the entire transition of the economy from stagnation to growth and further incorporates exports and the social return to variety, which enable us to conduct an empirically relevant quantitative analysis for Macau.

2.1 Household

Household's preferences are described by the lifetime utility function

$$U = \int_0^\infty e^{-(\rho-\lambda)t}\left[\ln c_t + \delta \ln(1-l_t) + \psi \frac{(\iota_t)^{1-\epsilon}}{1-\epsilon}\right] dt, \tag{1}$$

where c_t and ι_t denote per capita consumption of a domestic final good and an imported good, respectively. The parameter $\delta > 0$ measures household's preference for leisure $1 - l_t$, where l_t is per capita labor supply. In addition, $\rho > 0$ is the subjective discount rate, while $\lambda \in (0, \rho)$ is the population growth rate. $\psi > 0$ and $\epsilon \in [0, 1)$ are, respectively, the preference parameter and the inverse of the intertemporal elasticity of substitution for the imported good. The asset-accumulation equation is

$$\dot{a}_t = (r_t - \lambda)a_t + w_t l_t - c_t - p_t \iota_t, \tag{2}$$

where we choose the domestic final good as the numeraire. w_t denotes the real wage rate. r_t denotes the real interest rate and a_t denotes per capita asset value. Finally, p_t is the price of the imported good.

The Euler equation characterizes the optimal consumption path

$$\frac{\dot{c}_t}{c_t} = r_t - \rho. \tag{3}$$

Dynamic optimization yields the supply of labor

$$l_t = 1 - \frac{\delta c_t}{w_t}, \tag{4}$$

and the conditional demand function for the imported good

$$\iota_t = \left(\frac{\psi c_t}{p_t}\right)^{\frac{1}{\epsilon}}. \tag{5}$$

2.2 Domestic Final Good

Domestic competitive firms produce final good:

$$Y_t = \int_0^{N_t} X_t^{\theta}(i) \left[Z_t^{\alpha}(i) Z_t^{1-\alpha} \frac{L_{y,t}}{N_t^{1-\sigma}} \right]^{1-\theta} di, \tag{6}$$

where Y_t is the final output, and N_t measures the number of intermediate-good varieties. For each intermediate good i, $X_t(i)$ and $Z_t(i)$ denote its quantity and quality, respectively. The average quality is defined as $Z_t \equiv \int_0^{N_t} Z_t(i)di/N_t$. In addition, $1-\theta$ measures labor intensity, and $1-\alpha$ governs technology spillovers, where $\{\theta, \alpha\} \in (0,1)$. $L_{y,t}$ is production labor input. The parameter $\sigma \in (0,1)$ is the social return to variety, and $1-\sigma$ captures the congestion effect that removes the strong scale effect in our model.

Profit maximization implies the demand function for intermediate good i:

$$X_t(i) = \left[\frac{\theta}{P_t(i)} \right]^{\frac{1}{1-\theta}} Z_t^{\alpha}(i) Z_t^{1-\alpha} \frac{L_{y,t}}{N_t^{1-\sigma}}. \tag{7}$$

$P_t(i)$ denotes the price of intermediate good i. Under the zero-profit condition, payments to production labor and intermediate inputs satisfy

$$(1-\theta)Y_t = w_t L_{y,t}, \tag{8}$$

$$\theta Y_t = \int_0^{N_t} P_t(i) X_t(i) di. \tag{9}$$

2.3 Intermediate Goods and In-house R&D

Each monopolistic firm $i \in [0, N_t]$ produces its intermediate good i under a linear one-to-one technology. Therefore, producing $X_t(i)$ unit of intermediate good i requires $X_t(i)$ unit of the final good as input. Firm i also incurs an operating cost of $\phi Z_t^{\alpha}(i) Z_t^{1-\alpha}$ units of the final good, where the operating cost parameter $\phi > 0$. Before R&D, monopolistic firm i earns profit as

$$\Pi_t(i) = P_t(i) X_t(i) - X_t(i) - \phi Z_t^{\alpha}(i) Z_t^{1-\alpha}. \tag{10}$$

A higher quality level raises the demand for intermediate good i as shown in (7). To improve the quality of its product, firm i invests $R_t(i)$ units of the final good to conduct in-house R&D:

$$\dot{Z}_t(i) = R_t(i). \tag{11}$$

Monopolistic firm i's value is expressed as

$$V_t(i) = \int_t^{\infty} \exp\left(-\int_t^s r_u du \right) \left[\Pi_s(i) - R_s(i) \right] ds, \tag{12}$$

where $\Pi_s(i) - R_s(i)$ denotes the net profit after R&D. Firm i maximizes its value (12) subject to (7), (10) and (11). Dynamic optimization implies that each monopolistic firm i sets its markup price as

$$P_t(i) = \min\left\{ \mu, \frac{1}{\theta} \right\} = \mu, \tag{13}$$

where $\mu \in (1, 1/\theta)$ denotes the marginal cost of producing intermediate good i with quality level $Z_t(i)$ for competitive firms. To drive these competitive firms out of the market, the prices of intermediate goods are set to μ. Following previous studies, we assume a common initial quality level across intermediate goods, i.e., $Z_0(i) = Z_0$ for $i \in [0, N_t]$. This assumption leads to a symmetric equilibrium; namely, $Z_t(i) = Z_t$, $X_t(i) = X_t$ and $\Pi_t(i) = \Pi_t$ for $i \in [0, N_t]$. Under the symmetric equilibrium, the dynamic optimization of monopolistic firms yields the rate of return to quality-improving innovation

$$r_t^q = \alpha \left[(\mu - 1)\frac{X_t}{Z_t} - \phi \right], \tag{14}$$

which positively depends on quality-adjusted firm size, X_t/Z_t. Using (7), (13) and the symmetric condition $Z_t(i) = Z_t$ yields

$$\frac{X_t}{Z_t} = \left(\frac{\theta}{\mu}\right)^{\frac{1}{1-\theta}} \frac{L_{y,t}}{N_t^{1-\sigma}} = \left(\frac{\theta}{\mu}\right)^{\frac{1}{1-\theta}} \frac{L_t l_{y,t}}{N_t^{1-\sigma}}. \tag{15}$$

$l_{y,t}$ is the share of total labor L_t allocated to production. For simplicity, the state-variable component of the quality-adjusted firm size is defined as

$$x_t \equiv \left(\frac{\theta}{\mu}\right)^{\frac{1}{1-\theta}} \frac{L_t}{N_t^{1-\sigma}}. \tag{16}$$

In this notation, $x_t l_{y,t} = X_t/Z_t$ denotes the quality-adjusted firm size. Hereafter, we refer to quality-adjusted firm size simply as *firm size* when no confusion arises. Then, we re-express (14) as

$$r_t^q = \alpha \left[(\mu - 1) x_t l_{y,t} - \phi \right]. \tag{17}$$

2.4 Entrants

To seek positive monopolistic profits, new entrants supply differentiated intermediate goods, each characterized by the average quality level of Z_t.[9] Firms incur a sunk entry cost proportional to X_t, scaled by the entry-cost parameter $\beta > 0$. The free-entry condition takes the form

$$V_t = \beta X_t. \tag{18}$$

From the asset-pricing equation, the rate of return is determined as:

$$r_t = \frac{\Pi_t - R_t}{V_t} + \frac{\dot{V}_t}{V_t}. \tag{19}$$

We substitute (10), (11), (13), (15), (16) and (18) into (19) to obtain the rate of return to variety-expanding innovation

$$r_t^e = \frac{1}{\beta}\left(\mu - 1 - \frac{\phi + z_t}{x_t l_{y,t}}\right) + \frac{\dot{l}_{y,t}}{l_{y,t}} + \frac{\dot{x}_t}{x_t} + z_t, \tag{20}$$

where $z_t \equiv \dot{Z}_t/Z_t$ denotes quality growth. Consistent with the rate of return to quality-improving innovation in (17), the rate of return to variety-expanding innovation in (20) also positively depends on firm size, $x_t l_{y,t}$.

[9] Following Peretto (2015), we adopt this assumption to keep the model tractable.

2.5 Tourism and International Trade

Foreign tourists consume not only the domestic final good but also tourism services. To satisfy the demand for tourism services, $L_{s,t}$ units of labor are employed in the tourism sector.[10] Our model considers a small open economy where both foreign tourism demand and export demand are exogenous. In our setting, a constant share $\chi > 0$ of the final good is exported and a constant share $\tau > 0$ is consumed by foreign tourists. The parameter τ measures tourism demand; hereafter, we simply refer to τ as tourism. Labor employed in the tourism sector follows $L_{s,t} = \xi \tau l_t L_t$, where $\xi \in (0, 1/\tau)$.[11] Intuitively, an expansion in tourism τ increases labor demand for tourism services. The economy uses revenue from tourism and exports to pay for its imports. The balanced-trade condition is

$$p_t \iota_t L_t = \tau Y_t + w_t L_{s,t} + \chi Y_t. \tag{21}$$

2.6 Equilibrium

The equilibrium is defined as a collection of time paths of allocations $\{a_t, \iota_t, c_t, Y_t, L_{y,t}, L_{s,t}, l_t, l_{y,t}, l_{s,t}, X_t(i), R_t(i)\}$ and prices $\{r_t, w_t, p_t, P_t(i), V_t(i)\}$ that satisfy conditions as follows:

- the representative household chooses $\{c_t, l_t, \iota_t\}$ to maximize its lifetime utility, taking $\{r_t, w_t, p_t\}$ as given;
- competitive final-good firms choose factor inputs $\{L_{y,t}, X_t(i)\}$ to maximize profit, taking $\{w_t, P_t(i)\}$ as given;
- for each $i \in [0, N_t]$, monopolistic intermediate-good firm i chooses price and R&D investment $\{P_t(i), R_t(i)\}$ to maximize firm value $V_t(i)$, taking r_t as given;
- new entrants make entry decisions, taking V_t as given;
- the aggregate value of monopolistic firms is equal to the total value of household assets, such that $N_t V_t = a_t L_t$;
- the balanced-trade condition is satisfied, such that $p_t \iota_t L_t = \tau Y_t + w_t L_{s,t} + \chi Y_t$;
- the final-good market clears, $Y_t = c_t L_t + N_t(X_t + R_t + \phi Z_t) + \dot{N}_t \beta X_t + \tau Y_t + \chi Y_t$; and
- the labor market clears, with total labor allocated across production and tourism services $L_t l_t = L_{y,t} + L_{s,t} = L_t l_{y,t} + L_t l_{s,t}$.

[10] The requirement of labor for providing tourism services is the key characteristic that distinguishes the mechanism of tourism expansion from the export-led mechanism in Chu *et al.* (2023).

[11] Chu *et al.* (2024) simply set $\xi = 1$ in their model. We generalize this parameter in order to conduct an empirically relevant quantitative analysis for Macau.

2.7 Aggregation

Combining (6), (7) and (13), and imposing symmetry $Z_t = Z_t(i)$ for $i \in [0, N_t]$, we derive the aggregation production function for the final good in equilibrium:

$$Y_t = \left(\frac{\theta}{\mu}\right)^{\frac{\theta}{1-\theta}} N_t^{\sigma} Z_t L_{y,t} = \left(\frac{\theta}{\mu}\right)^{\frac{\theta}{1-\theta}} N_t^{\sigma} Z_t L_t l_{y,t}, \tag{22}$$

where the second equity uses $L_{y,t} = L_t l_{y,t}$. Defining per capita domestic final output as $y_t \equiv Y_t/L_t$, its growth rate is

$$g_t \equiv \frac{\dot{y}_t}{y_t} = \sigma n_t + z_t + \frac{\dot{l}_{y,t}}{l_{y,t}}, \tag{23}$$

where $n_t \equiv \dot{N}_t/N_t$ and $z_t \equiv \dot{Z}_t/Z_t$, respectively, denote the growth rates of variety and quality.

2.8 Dynamics

According to (17) and (20), a larger firm size leads to a higher rate of return to innovation. This implies that innovation becomes more profitable as firm size increases. We consider a realistic sequence in which variety-expanding innovation comes before quality-improving innovation, which is consistent with the pattern observed in advanced economies. Our model features two threshold values of firm size that activate variety-expanding and quality-improving innovation, respectively.[12] When firm size x_t reaches the first threshold x_N, variety expansion becomes profitable and begins to take place. Then, when it reaches the second threshold x_Z, quality improvement becomes profitable and begins to take place. We impose the following parameter condition to ensure stability of our model:

$$\beta\phi > \frac{1}{\alpha}\left[\mu - 1 - \beta\left(\rho + \frac{\sigma\lambda}{1-\sigma}\right)\right] > \mu - 1. \tag{24}$$

According to (16), the state variable x_t evolves as follows:

$$\frac{\dot{x}_t}{x_t} = \lambda - (1-\sigma)n_t. \tag{25}$$

As we will show in Section 3, variety growth n_t is a monotonically increasing function in x_t. Therefore, (25) characterizes a stable dynamic process, and x_t eventually converges to its steady-state level, denoted as x^*.

Given the parameter condition specified in (24), the economy evolves through three phases: (1) In the pre-industrial era, the state variable $x_t \le x_N$ and firm size remains below the threshold for variety expansion. At this early stage, innovation is not profitable, so neither variety expansion nor quality improvement occurs.[13] (2) In the first phase of the industrial era, the state variable $x_N < x_t \le x_Z$, firm size exceeds the first threshold, making variety

[12] See the derivation in Section 3.

[13] We assume that intermediate goods are produced by competitive firms with a constant marginal cost of μ before the industrial era. In Appendix B, we also explore an alternative scenario where monopolistic firms engage in production in the pre-industrial era; however, the dynamics become less realistic.

expansion profitable. In this phase, variety-expanding innovation takes place, but quality-improving innovation remains absent because firm size has not yet reached the second threshold. (3) In the second phase of the industrial era, the state variable x_t exceeds the second threshold x_Z. In this phase, firm size is sufficiently large to support both variety expansion and quality improvement. In the long run, the economy approaches a balanced growth path as the state variable x_t converges to its steady-state value x^*.

Before analyzing how tourism expansion affects the entire transition of the economy, we present the steady-state properties of the consumption-output ratio and production labor share in Lemma 1.

Lemma 1 *(Consumption-output ratio and production labor share) Assume that* $1-\theta-\tau-\chi > 0$. *At any time t, both the consumption-output ratio c_t/y_t and production labor share $l_{y,t}$ adjust instantaneously to their unique steady-state values and remain constant thereafter. The steady-state expressions for the consumption-output ratio and production labor share are given by:*

$$\frac{c_t}{y_t} = \left(\frac{c_t}{y_t}\right)^* = \begin{cases} 1-\theta-\tau-\chi & 0 \le x_t \le x_N \\ \frac{(\rho-\lambda)\beta\theta}{\mu} + 1-\theta-\tau-\chi & x_N < x_t < \infty \end{cases}; \tag{26}$$

$$l_{y,t} = l_y^* = \begin{cases} \left[\frac{1}{1-\xi\tau} + \frac{\delta}{1-\theta}(1-\theta-\tau-\chi)\right]^{-1} & 0 \le x_t \le x_N \\ \left\{\frac{1}{1-\xi\tau} + \frac{\delta}{1-\theta}\left[\frac{(\rho-\lambda)\beta\theta}{\mu} + 1-\theta-\tau-\chi\right]\right\}^{-1} & x_N < x_t < \infty \end{cases}. \tag{27}$$

Proof. See Appendix B. ■

By differentiating the production labor share in (27) with respect to tourism τ, we obtain

$$\frac{\partial l_y^*}{\partial \tau} = \left(l_y^*\right)^2 \left[\frac{\delta}{1-\theta} - \frac{1}{(1-\xi\tau)^2}\right]. \tag{28}$$

If and only if the following condition holds, tourism expansion raises the production labor share

$$\tau < \frac{1}{\xi}\left(1 - \sqrt{\xi\frac{1-\theta}{\delta}}\right). \tag{29}$$

If $\delta < \xi(1-\theta)$, (29) never holds, so that an expansion in tourism reduces production labor share. If $\delta > \xi(1-\theta)$, the effect of tourism expansion on production labor share follows an inverted-U pattern. Specifically, the effect of an expansion in tourism is positive when $\xi\tau < 1 - \sqrt{\xi(1-\theta)/\delta}$, but becomes negative when $\xi\tau > 1 - \sqrt{\xi(1-\theta)/\delta}$. The economic intuition is as follows. An expansion in tourism increases the demand for both the domestic final good and local tourism services, which reflects two opposing effects: the employment effect and the reallocation effect. On the one hand, the expansion of market size requires more labor, which increases the overall employment. On the other hand, the higher demand for tourism services may attract labor away from production to the tourism sector. When leisure preference is weak, households already devote most of their available time to work. In this case, even an expansion in tourism cannot significantly increase labor supply. As a result, the employment effect is small and the reallocation effect always dominates. Therefore, under weak leisure preference, an expansion in tourism reduces the production labor share. When leisure preference is strong, the reliance on tourism determines which effect dominates. Specifically, if the economy has low reliance on tourism, job opportunities in the tourism sector are relatively limited, so the reallocation effect is small and the employment effect dominates. In contrast, if the economy is highly reliant on tourism, most of the additional labor is drawn into the tourism sector, and the reallocation effect dominates. Therefore, under strong leisure preference, an expansion in tourism increases the production labor share when the economy has a low tourism share, while it decreases the production labor share when the tourism share is high.

3 Tourism and Takeoff

This section explores how tourism shapes the dynamic transition of the economy from stagnation in the pre-industrial era to innovation-driven growth in the industrial era. After presenting analytical results, we empirically test the theoretical predictions using cross-country panel data.

3.1 The Pre-Industrial Era

In the pre-industrial era, neither variety expansion nor quality improvement occurs because firm size is too small to make innovation profitable, i.e., $n_t = z_t = 0$. Lemma 1 suggests that production labor share remains constant over time, so that $\dot{l}_{y,t}/l_{y,t} = 0$. Using (23), per capita final output growth is given by

$$g_t = \sigma n_t + z_t + \frac{\dot{l}_{y,t}}{l_{y,t}} = 0. \tag{30}$$

Imposing $n_t = 0$ in (25) gives the evolution of the state variable x_t

$$\frac{\dot{x}_t}{x_t} = \lambda - (1-\sigma)n_t = \lambda. \tag{31}$$

Therefore, x_t grows at a constant rate $\lambda > 0$ in this era. As a result, firm size $x_t l_y^*$ would exceed the threshold for variety-expanding innovation within finite time, thereby leading the economy to enter the first industrial phase.

3.2 The First Phase of the Industrial Era

In the first industrial phase, variety expansion becomes active (i.e., $n_t > 0$), while quality improvement still remains absent (i.e., $z_t = 0$). Using (3), (23), $z_t = 0$, $g_t \equiv \dot{y}_t/y_t = \dot{c}_t/c_t$ and $\dot{l}_{y,t}/l_{y,t} = 0$ yields variety growth as

$$n_t = \frac{1}{\beta}\left(\mu - 1 - \frac{\phi}{x_t l_y^*}\right) + \lambda - \rho, \tag{32}$$

which is positive if and only if firm size exceeds the first threshold:

$$x_t l_y^* > \frac{\phi}{\mu - 1 - \beta(\rho - \lambda)}. \tag{33}$$

In other words, the economy enters the first industrial phase when

$$x_t > x_N \equiv \frac{\phi}{\mu - 1 - \beta(\rho - \lambda)} \frac{1}{l_y^*}. \tag{34}$$

This implies that x_N is decreasing in production labor share l_y^*. Let x_0 denote the initial value of the state variable x_t. Since x_t grows at the constant rate λ in the pre-industrial era, the timing of takeoff is given by $T_N = (\ln x_N - \ln x_0)/\lambda$. A higher production labor share lowers x_N, leading to a smaller value of T_N and thus an earlier takeoff.

We combine (23) and (32) to obtain the transitional growth rate during this phase

$$g_t = \sigma n_t = \frac{\sigma}{\beta}\left(\mu - 1 - \frac{\phi}{x_t l_y^*}\right) - \sigma(\rho - \lambda), \tag{35}$$

which is increasing in production labor share l_y^*. Given the comparative statics of the production labor share with respect to tourism τ, Proposition 1 summarizes the effects of tourism in the first industrial phase.

Proposition 1 *(The effect of an expansion in tourism in the first phase of the industrial era) With $\delta < \xi(1-\theta)$, leisure preference is weak; in this case, an increase in tourism share delays takeoff from stagnation to innovation-driven growth and lowers its transitional growth. With $\delta > \xi(1-\theta)$, leisure preference is strong; in this case, the effects of tourism expansion on takeoff and transitional growth follow an inverted-U pattern: it leads to an earlier (a delayed) takeoff and raises (lowers) the transitional growth rate when tourism reliance is low (high).*

Proof. Proven in text. ■

In this phase, (25) and (32) characterize the dynamics of the state variable x_t

$$\frac{\dot{x}_t}{x_t} = \lambda - (1-\sigma)\left[\frac{1}{\beta}\left(\mu - 1 - \frac{\phi}{x_t l_y^*}\right) + \lambda - \rho\right]. \tag{36}$$

Given the parameter condition (24), the state variable x_t keeps growing and exceeds x_Z within finite time. At that point, firm size $x_t l_y^*$ crosses the threshold for quality improvement, and the economy transitions into the second industrial phase.

3.3 The Second Phase of the Industrial Era

Both variety expansion and quality improvement are active (i.e., $n_t > 0$ and $z_t > 0$) in the second industrial phase. Combining (3), (17), (20), (23), $g_t \equiv \dot{y}_t/y_t = \dot{c}_t/c_t$ and $\dot{l}_{y,t}/l_{y,t} = 0$ yields variety growth and quality growth, respectively:

$$n_t = \frac{(1-\alpha)(\mu-1) - \beta(\rho-\lambda) - [(1-\alpha)\phi - \rho]\frac{1}{x_t l_y^*}}{\beta - \frac{\sigma}{x_t l_y^*}}, \tag{37}$$

$$z_t = \frac{\beta\left\{\left(\alpha - \frac{\sigma}{\beta x_t l_y^*}\right)[(\mu-1)x_t l_y^* - \phi] - [(1-\sigma)\rho + \sigma\lambda]\right\}}{\beta - \frac{\sigma}{x_t l_y^*}}. \tag{38}$$

From (38), quality growth becomes positive once firm size exceeds the second threshold Ψ:

$$x_t l_y^* > \underset{\Psi}{\arg solve}\left\{[(\mu-1)\Psi-\phi]\left(\alpha-\frac{\sigma}{\beta\Psi}\right)=(1-\sigma)\rho+\sigma\lambda\right\}. \tag{39}$$

It implies that the economy enters the second industrial phase when $x_t > x_Z \equiv \Psi/l_y^*$ is satisfied.

Combining (3), (17) and $g_t \equiv \dot{y}_t/y_t = \dot{c}_t/c_t$ yields per capita output growth in the second industrial phase as

$$g_t = \alpha\left[(\mu-1)x_t l_y^* - \phi\right] - \rho, \tag{40}$$

which is increasing in production labor share l_y^*. Therefore, the effect of an expansion in tourism on transitional growth depends on how production labor share responds to an expansion in tourism, as shown in Lemma 1.

Substituting (37) into (25) yields the evolution of x_t in this phase

$$\frac{\dot{x}_t}{x_t} = \frac{1-\sigma}{\beta-\frac{\sigma}{x_t l_y^*}}\left\{\left[(1-\alpha)\phi-\left(\rho+\frac{\sigma\lambda}{1-\sigma}\right)\right]\frac{1}{x_t l_y^*}-\left[(1-\alpha)(\mu-1)-\beta\left(\rho+\frac{\sigma\lambda}{1-\sigma}\right)\right]\right\}. \tag{41}$$

Under the parameter condition in (24), the state variable x_t continues to grow and converges to its steady-state value

$$x^* = \frac{(1-\alpha)\phi-\left(\rho+\frac{\sigma\lambda}{1-\sigma}\right)}{(1-\alpha)(\mu-1)-\beta\left(\rho+\frac{\sigma\lambda}{1-\sigma}\right)}\frac{1}{l_y^*}. \tag{42}$$

We substitute (42) into (40) to obtain the steady-state growth rate

$$g^* = \alpha\left[(\mu-1)\frac{(1-\alpha)\phi-[\rho+\sigma\lambda/(1-\sigma)]}{(1-\alpha)(\mu-1)-\beta[\rho+\sigma\lambda/(1-\sigma)]}-\phi\right]-\rho>0, \tag{43}$$

which is independent of production labor share and therefore unaffected by tourism. This neutrality arises from the endogenous market structure in our model, under which firm size eventually converges to a stationary level. Proposition 2 summarizes the effects of tourism in the second industrial phase.[14]

Proposition 2 *(The effect of an expansion in tourism in the second phase of the industrial era) With $\delta < \xi(1-\theta)$, leisure preference is weak; in this case, an increase in tourism share lowers the transitional growth rate g_t. With $\delta > \xi(1-\theta)$, leisure preference is strong; in this case, the effect of tourism expansion on transitional growth follows an inverted-U pattern: it raises (lowers) the transitional growth rate when tourism reliance is low (high). In both cases, the steady-state growth rate is unaffected by tourism.*

Proof. Proven in text. ■

[14]The model in Chu *et al.* (2024) is essentially a special case of the second industrial phase in our model. They set both the export share χ and the social return to variety σ to zero. We relax these parameter restrictions to allow for a more realistic quantitative analysis.

3.4 Empirical Evidence

A large empirical literature studies the link between tourism development and economic growth. Early studies by Balaguer and Cantavella-Jorda (2002) and Gunduz and Hatemi-J (2005) use time-series data to test the tourism-led growth hypothesis (TLGH) in specific countries. Subsequent work adopts cross-country panel data to examine TLGH more broadly; see for example Brau *et al.* (2007), Lee and Chang (2008), Sequeira and Nunes (2008), Figini and Vici (2010) and Antonakakis *et al.* (2016). More recent studies document nonlinear patterns between tourism development and economic growth; see for example, Chiu and Yeh (2017), De Vita and Kyaw (2017), Zuo and Huang (2018), Antonakakis *et al.* (2019) and Dogan and Zhang (2023). However, these studies basically use GDP or GDP per capita as the growth measure, which mechanically includes tourism revenues and thus makes it difficult to isolate the effect of tourism on innovation in non-tourism sectors.[15] Our empirical analysis complements this literature by employing cross-country panel data with the log of total factor productivity and the log of non-tourism GDP as novel proxies for growth, which allows us to explicitly document the relationship between tourism and innovation-driven growth in non-tourism sectors.

We use cross-country panel data to empirically test the inverted-U relationship between tourism and economic growth.[16] The estimation specification is given by

$$g_{jt} = \kappa_1 tour_{jt} + \kappa_2 tour_{jt}^2 + \Gamma\Phi_{jt} + \zeta_j + \zeta_t + \varepsilon_{jt}.$$

We use five-year average data to mitigate the potential bias caused by the cyclical fluctuation in annual data. g_{jt} denotes economic growth in country j in period t, measured by either the log of TFP index or the log of non-tourism GDP. Tourism development $tour_{jt}$ is measured by the log level of tourist arrivals. Under empirically plausible values, our theory expects that $\kappa_1 > 0$ and $\kappa_2 < 0$, implying an inverted-U relationship between tourism and innovation. Φ_{jt} is a set of control variables that include the government expenditure share of GDP, the human capital index, the depreciation rate, and the real interest rate. We also consider country fixed effects ζ_j and period fixed effects ζ_t. ε_{jt} denotes the error term.

We merge data from Penn World Table and World Bank Data, obtaining a sample of up to 481 observations for 109 countries over 1996–2020.[17] Table 1 reports the estimation results. Columns (1)-(2) use the log level of total factor productivity as the dependent variable, while columns (3)-(4) use the log level of non-tourism GDP. In all columns, κ_1 is positive and statistically significant, and κ_2 is negative and statistically significant. This empirical finding aligns with our theoretical prediction of the non-monotonic inverted-U relationship between tourism and innovation.

4 Quantitative Analysis

Our theory suggests that although tourism does not affect the long-run growth rate, it plays an important role in affecting transitional growth. This motivates a quantitative analysis that focuses on the transition path rather than balanced-growth outcomes. By calibrating the model

[15] Tzeremes (2022) employs TFP as the proxy for growth, but it only focuses on Latin American countries.

[16] In Section 4, our calibrated values of parameters show that $\delta > \xi(1-\theta)$. We therefore focus on this empirically relevant case and test the inverted-U pattern in our empirical analysis.

[17] Summary statistics are reported in Table A.1.

Table 1: Relationship between tourism shocks and economic growth

Dependent variable:	log TFP		log non-tourism GDP	
	(1)	(2)	(3)	(4)
$tour_{jt}$	0.450***	0.376***	1.328**	1.484***
	(0.135)	(0.127)	(0.544)	(0.535)
$tour_{jt}^2$	-0.013***	-0.011***	-0.040**	-0.046**
	(0.005)	(0.005)	(0.019)	(0.018)
Control variables		✓		✓
Country fixed effects	✓	✓	✓	✓
Period fixed effects	✓	✓	✓	✓
Observations	462	462	159	159
R^2	0.705	0.767	0.998	0.998

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. *Robust standard errors are reported in parentheses, clustered at the country level.*

to Macau's data, we examine how tourism expansion quantitatively affects technological growth in Macau. As an economy reliant on tourism, Macau has experienced significant changes in the tourism share of GDP since its return to China in 1999, making it a suitable case for studying between tourism development and technological progress.

Our model features a set of parameters: $\{\lambda, \theta, \rho, \alpha, \sigma, \mu, \beta, \chi, \delta, \phi, \xi, \tau\}$.[18] We assign the population growth rate λ to 1.0%.[19] The labor intensity $1 - \theta$ and the subjective discount rate ρ are, respectively, fixed at conventional values of 0.5 and 0.05. Following the calibration strategy in Iacopetta *et al.* (2019), we set the social return to variety σ and the degree of technology spillovers $1 - \alpha$ to 0.25 and 0.833, respectively. Also, we set the markup ratio μ to 1.5. The remaining parameters $\{\beta, \chi, \delta, \phi, \xi, \tau_{aver}\}$ are jointly calibrated by the following moments: 15.8% for resident domestic goods consumption share of GDP,[20] 6.0% for the share of exported goods in GDP,[21] 0.5% for the long-run TFP growth rate,[22] 47.5% for tourism value added as a share of GDP,[23] 49.7% for the tourism employment share,[24] and 0.3 for working hours share in total available time. Table 2 reports calibrated parameter values.

The calibrated values of δ, θ and ξ imply that $\delta > \xi(1 - \theta)$. According to our model, it gives rise to an inverted-U pattern between tourism expansion and technological growth. Based on (29), this inverted-U relationship reaches its turning point when tourism accounts

[18]The preference parameter ψ only affects consumption of the imported good ι but does not affect other equilibrium outcomes.

[19]Data source: World Bank Data.

[20]Macau's consumption share of GDP is much lower than in most economies because it is a tourism-dependent small open economy. In some years, Macau's exports of services account for nearly 80% of its GDP, resulting in a high net export share and thus a low consumption share of GDP. Data source: DSEC Macau Data.

[21]Data source: CEPII Data.

[22]We use TFP growth instead of GDP growth in the calibration since our model emphasizes innovation-driven growth. Data source: Federal Reserve Bank of St. Louis.

[23]Data source: DSEC Macau Data.

[24]Data source: DSEC Macau Data.

Table 2: Calibrated values of parameters

λ	θ	ρ	α	σ	μ	β	χ	δ	ϕ	τ_{aver}	ξ
0.010	0.500	0.050	0.167	0.250	1.500	1.627	0.060	9.826	1.559	0.216	2.305

for 63.5% of GDP.[25] In other words, an expansion in tourism raises Macau's TFP growth rate when the tourism share is below 63.5%, but lowers it when the tourism share exceeds 63.5%. This is consistent with what we observe in Macau's data: outside the period 2010-2013 (i.e., when the tourism share of GDP is below 63.5%), tourism share and TFP growth move in the same direction. However, during 2010-2013 (i.e., when the tourism share exceeds 63.5%), the relationship reverses: tourism expansion is associated with lower TFP growth.

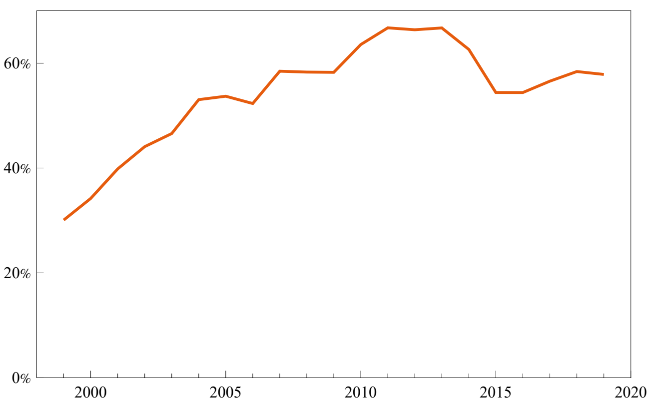

Figure 1: Tourism share of GDP

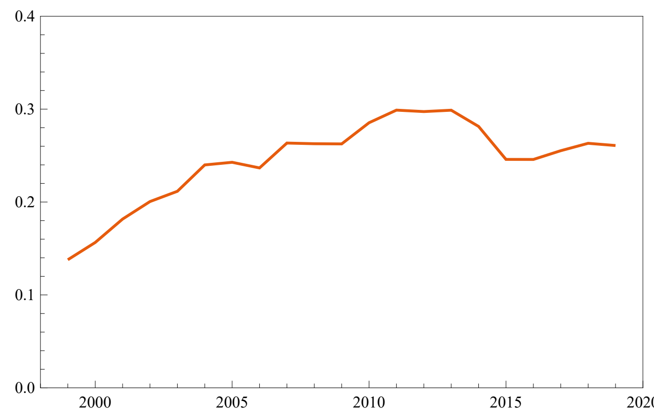

Figure 2: Calibrated path of τ

In addition, we conduct a simulation to examine the quantitative effects of tourism on Macau's technological growth rate. Figure 1 illustrates the path of tourism share of GDP in Macau. The tourism share fluctuates over time but generally rises from 30.1% in 1999 to 57.8% in 2019, with a peak of 66.7% in 2013. Using the observed time series of tourism share of GDP, we take the changes in tourism share as a sequence of exogenous shocks and calibrate the path of τ (see Figure 2). In the simulation, we hold all other parameters constant and and only allow the calibrated time-varying path of τ to evolve. Therefore, the simulated growth is driven solely by tourism. Figure 3 plots the simulated growth rate from our model and the HP-filter trend of Macau's TFP growth. The simulated path aligns reasonably well with the trend of TFP growth in the data, especially before 2014. The discrepancy after 2014 may be partly explained by Macau's stricter standards on skilled immigration introduced in 2014 and on major investment immigration implemented in 2015, both of which likely lead to the sharp decline in TFP growth. However, it is worth noting that while the simulated TFP growth rate deviates from the observed data after 2014, the direction of change remains largely consistent. Our simulated TFP growth rate shows a decline from 0.028 in 2010 to 0.009 in 2019, while the data shows a decline from 0.030 to -0.069 over the same period. These results suggest that

[25] The tourism share of GDP is given by $1 - (1 - \tau)/[(1 - \theta)\xi\tau/(1 - \xi\tau) + 1]$.

tourism accounts for roughly one-fifth of the observed decline in Macau's TFP growth since 2010.

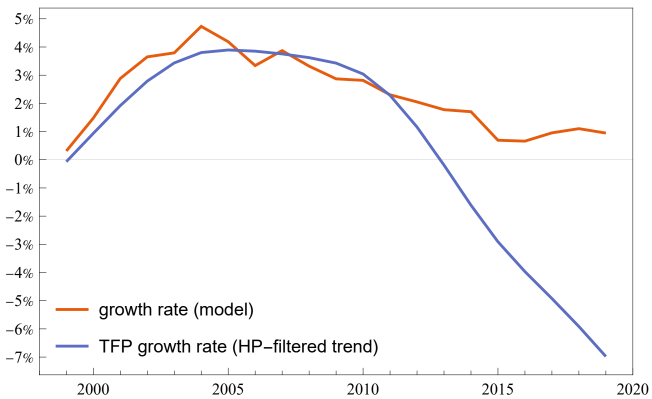

Figure 3: Simulation and data

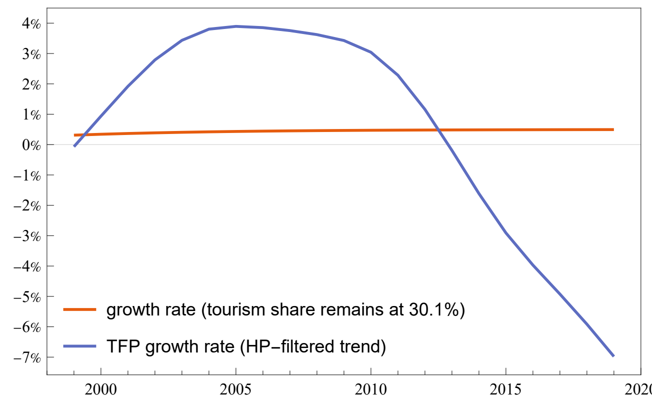

Figure 4: Counterfactual

We also conduct a counterfactual analysis by holding the tourism share of GDP at its initial level of 30.1%. In this case, the counterfactual growth rate increases very slowly and remains at a low level, which does not match the observed TFP growth rate in Macau. The comparison between this counterfactual experiment and the baseline simulation suggests that the rapid growth in Macau after its return to China is largely driven by the substantial rise in its tourism share.

5 Conclusion

This study develops a small-open-economy Schumpeterian growth model with a tourism sector and endogenous takeoff to study how tourism shapes the transition from stagnation to innovation-driven growth. The model highlights two opposing mechanisms through which tourism affects the economy. On the one hand, tourism expansion raises labor demand and thus total employment, which hastens takeoff and leads to faster transitional growth. On the other hand, a higher demand for tourism services reallocates labor away from production toward the tourism sector, delaying takeoff and dampening transitional growth. These two opposing effects of tourism expansion generate a non-monotonic relationship between tourism and growth. Specifically, when the economy has relatively low reliance on tourism, the employment effect dominates, which leads to positive effects on both takeoff and transitional growth. However, when the reliance on tourism is high, the reallocation effect becomes dominant, delaying takeoff and reducing transitional growth. Using cross-country panel data, we provide supportive empirical evidence for this inverted-U pattern: the positive effect of tourism on growth weakens and even becomes negative when the tourism share is sufficiently high. Our quantitative analysis calibrates the model to Macau's data and suggests that tourism expansion increases Macau's TFP growth when tourism accounts for less than 63.5% of GDP, but reduces its TFP growth when this turning point is exceeded. Moreover, changes in tourism explain roughly one-fifth of the observed decline in TFP growth in Macau.

Overall, our findings indicate that excessive dependence on tourism may impede the transition to sustained innovation-driven growth. This insight has direct policy relevance for tourism-dependent economies such as Macau, which has implemented a diversification development strategy aiming to reduce overdependence on tourism-related industries and promote sustained growth.

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Appendix

A Data

Table A.1: Summary statistics

Variables	Observations	Mean	Sd	Min	Max
Log TFP index	481	-0.030	0.158	-1.097	0.730
Log non-tourism GDP	159	25.644	1.787	21.925	30.458
Log tourist arrivals	462	15.048	1.788	8.556	19.122
Human capital index	481	2.635	0.670	1.098	4.072
Government expenditure share of GDP	481	0.175	0.059	0.037	0.368
Capital depreciation rate	481	0.044	0.011	0.021	0.100
Real interest rate	481	0.119	0.072	0.010	0.414

Data source: World Bank Data for tourist arrivals. Penn World Table for other variables.

B Proofs

Proof of Lemma 1. In the pre-industrial era, innovation is absent and the asset value is zero, so there is no asset accumulation. We combine $\dot{a}_t = 0$, (2), (8), (21) to obtain

$$\frac{c_t}{y_t} = \frac{w_t l_t - p_t \iota_t}{y_t} = 1 - \theta - \tau - \chi, \tag{B.1}$$

which is positive if and only if $1 - \theta - \tau - \chi > 0$.

In the industrial era, the free-entry condition (18) holds due to the entry of new firms. Imposing symmetry, we use (9), (13), $N_t V_t = a_t L_t$ and the free-entry condition to derive

$$a_t = \frac{\beta\theta}{\mu} y_t. \tag{B.2}$$

Combining (2), (3), (8), (21) and (B.2) yields

$$\frac{\dot{c}_t}{c_t} - \frac{\dot{y}_t}{y_t} = \frac{\mu}{\beta\theta}\frac{c_t}{y_t} - \left[\frac{\mu(1-\theta-\tau-\chi)}{\beta\theta} + \rho - \lambda\right], \tag{B.3}$$

which says that the consumption-output ratio jumps to its steady-state value $(c_t/y_t)^*$ and remains constant in the industrial era. We then use the supply of labor (4), the demand of labor (8) and $l_{y,t} = (1 - \xi\tau) l_t$ to derive the expression for production labor share as

$$l_{y,t} = \left(\frac{1}{1-\xi\tau} + \frac{\delta}{1-\theta}\frac{c_t}{y_t}\right)^{-1}. \tag{B.4}$$

Substituting the stationary values of the consumption-output ratio into (B.4) yields the stationary values of production labor share for both the pre-industrial and industrial eras, as summarized in Lemma 1. ■

An alternative scenario in the pre-industrial era. We further explore an alternative scenario in our model, where monopolistic firms operate even in the pre-industrial era. Using (10), (13), $X_t/Z_t = x_t l_{y,t}$, and imposing symmetry, we can express the profit of monopolistic firms as

$$\Pi_t = [(\mu - 1)x_t l_{y,t} - \phi]\, Z_t, \tag{B.5}$$

which is increasing in firm size $x_t l_{y,t}$. In this scenario, monopolistic firms operate and earn positive profits in the pre-industrial era. Specifically, $\Pi_t > 0$ when $x_0 \leq x_t < x_N$. Based on (B.5), this condition is satisfied if and only if

$$x_0 l_{y,0} > \frac{\phi}{\mu - 1}, \tag{B.6}$$

where $x_0 l_{y,0}$ is the initial firm size.

Since firms do not invest in innovation (i.e., $R_t = 0$) in the pre-industrial era, (19) becomes

$$r_t = \frac{\Pi_t}{V_t} + \frac{\dot{V}_t}{V_t}. \tag{B.7}$$

We combine (2), $a_t L_t = N_t V_t$ and $n_t = 0$ to derive

$$\frac{\dot{a}_t}{a_t} = \frac{\dot{V}_t}{V_t} - \lambda = r_t - \lambda + \frac{w_t l_t - c_t - p_t \iota_t}{a_t}. \tag{B.8}$$

Using $\dot{a}_t = 0$, (B.7) and (B.8) yields

$$c_t = \frac{\Pi_t}{V_t} a_t + w_t l_t - p_t \iota_t = \frac{N_t}{L_t} \Pi_t + (1 - \theta - \tau - \chi)\, y_t, \tag{B.9}$$

where the second equality uses $a_t L_t = N_t V_t$, $p_t \iota_t = \tau y_t + w_t l_{s,t} + \chi y_t$, $w_t l_{y,t} = (1-\theta)\, y_t$ and $l_{y,t} + l_{s,t} = l_t$. We then impose symmetry, and substitute (10) and (13) into (B.9) to derive

$$c_t = \frac{N_t}{L_t}[(\mu - 1)X_t - \phi Z_t] + (1 - \theta - \tau - \chi)\, y_t = \frac{\theta}{\mu}\left(\mu - 1 - \frac{\phi}{x_t l_{y,t}}\right) y_t + (1 - \theta - \tau - \chi)\, y_t, \tag{B.10}$$

where the second equality uses $\theta Y_t = \mu N_t X_t$ and $X_t/Z_t = x_t l_{y,t}$. We rearrange (B.10) to express the consumption-output ratio in the pre-industrial era as

$$\frac{c_t}{y_t} = \frac{\theta}{\mu}\left(\mu - 1 - \frac{\phi}{x_t l_{y,t}}\right) + 1 - \theta - \tau - \chi. \tag{B.11}$$

The consumption-output ratio would increase from $1 - \theta - \tau - \chi$ to $1 - \theta - \tau - \chi + (\rho - \lambda)\beta\theta/\mu$ if firm size $x_t l_{y,t}$ starts from $\phi/(\mu - 1)$ and increases toward $\phi/[\mu - 1 - \beta(\rho - \lambda)]$, which is the threshold for variety expansion as shown in (33). Finally, we use (B.4) and (B.11) to derive the expression for firm size $x_t l_{y,t}$ in the pre-industrial era

$$x_t l_{y,t} = \frac{x_t + \frac{\theta}{1-\theta}\frac{\delta\phi}{\mu}}{\frac{1}{1-\xi\tau} + \delta\left(1 + \frac{\mu-1}{\mu}\frac{\theta}{1-\theta} - \frac{\tau+\chi}{1-\theta}\right)}. \tag{B.12}$$

Given that the law of motion for x_t in (25) and $n_t = 0$ in the pre-industrial era, firm size $x_t l_{y,t}$ gradually increases towards the threshold $\phi/[\mu - 1 - \beta(\rho - \lambda)]$ and then triggers the takeoff as in the baseline model. The only difference here is that, as x_t increases over time, $l_{y,t}$ in (B.12) gradually decreases (instead of jumping at the time of the takeoff). This additional dynamics of $l_{y,t}$ implies negative growth in per capita final output in the pre-industrial era, which is less realistic than the dynamics in the baseline model. ■