THREE ESSAYS ON ECONOMIC GROWTH IN SINGAPORE

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ABSTRACT

This dissertation is a collection of three relatively independent essays on economic growth in Singapore. In the first chapter, I construct a low-frequency macroeconometric model to investigate the association between eight key macroeconomic variables, consisting of FDI net inflows, gross fixed capital formation, openness to trade, labor compensation, unit labor costs, domestic credit to private sector, real interest rate, and capital stock, and a variety of relevant macroeconomic variables in Singapore for the period 1980-2009. The model contains two submodels: a multivariate autoregressive integrated moving average (ARIMA) model and an enhanced first-order autoregressive distributed lag (ADL) model. My results are broadly consistent with evidence from previous empirical studies, and have important policy implications for characterizing Singapore's medium- and long-term growth path.

The second chapter re-estimates the contributions of various inputs to Singapore's output growth for the period 1980-2009. To address the impact of quality-adjusted human capital and time-varying factor shares on these contributions, I extend the translog production function approach developed by Jorgenson et al. (1987) by incorporating human-capital-adjusted labor and the assumption of time-varying shares of physical capital. The results show that a decline in capital deepening is partly offset by improvements in labor quality and procyclical productivity growth. They also imply that estimation of contributions of various inputs without considering quality-adjusted labor input is biased.

In the third chapter, I measure the contemporaneous and one-period-lagged effects of the level of economic development, R&D spending, FDI net inflows, and infrastructure on innovation using a unique panel data set of 17 Group of Twenty (G20) countries and the European Union (EU) as a whole for the period 1996-2011. Additionally, I examine and compare the innovation trends in Singapore with the empirical results in different country groups of the G20 to explore the determinants of innovation in Singapore. This essay highlights the economic importance of R&D spending and infrastructure relative to that of FDI net inflows and the level of economic development addressed in traditional studies. It also implies that routinely pooling developed and developing countries can result in misleading conclusions and inappropriate policy recommendations. Besides relying on infrastructure to promote innovation, Singapore ought to apply R&D and technology spillovers to domestic enterprises more efficiently.

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CHAPTER 1

EXPLORING THE RELATIONSHIP BETWEEN MACROECONOMIC VARIABLES: A SMALL MACROECONOMETRIC MODEL OF THE SINGAPOREAN ECONOMY

1.1 Introduction

As one of the four Asian Tigers[1] that have grown rapidly over the past few decades, Singapore is viewed as a good example of economic growth in small open economies. For example, it is the highest-priority investment target in terms of operating conditions, political risk, and the foreign exchange/external accounts position[2]. According to the overall ease of doing business ranking 2012, the city-state is ranked top in the world with respect to the ease of starting a business, resolving insolvency, and trading across borders[3].

Previous studies have shed light on certain key macroeconomic variables of the Singaporean economy. For example, Parrado (2004) claims that Singapore's exchange-rate-centered monetary policy has had a forward-looking orientation toward stabilizing domestic inflation and output. Blanchard and Fischer (1992) find it difficult for foreign direct investment (FDI) and public domestic investment to spur technological progress and capital accumulation in Singapore. However, there are only a limited number of

[1] The East Asian economies of Hong Kong, Singapore, South Korea, and Taiwan whose average annual growth rates of real GDP were about 6% during the 1960s and 1990s.
[2] Business Risk Service 2011-II.
[3] Doing Business 2012: Doing Business in a More Transparent World.

macroeconometric models of the Singaporean economy, such as the Monetary Model of Singapore (MMS), the Satellite Model of Singapore (SMS), and the Econometric Studies Unit (ESU01) model, that include all types of macroeconomic variables and explore the relationship between them. Moreover, the data source and detailed method description of these models are not easily accessible. This essay attempts to fill the gap in the literature by applying public data sources, such as the World Bank's World Development Indicators (WDI), to a low-frequency macroeconometric model based on Klein et al. (2008) and Klein et al. (2012).

In this essay, I construct a low-frequency macroeconometric model to investigate the association between eight key macroeconomic variables, consisting of FDI net inflows, gross fixed capital formation, openness to trade, labor compensation, unit labor costs, domestic credit to private sector, real interest rate, and capital stock, and a variety of relevant macroeconomic variables in Singapore for the period 1980-2009. The variable selection complements the existing literature by including some labor market variables, such as labor compensation and unit labor costs, and domestic credit to private sector that are rarely studied in the literature of the Singaporean economy.

The model contains two submodels: a multivariate autoregressive integrated moving average (ARIMA) model (also known as an ARIMA model with explanatory variables) and an enhanced first-order autoregressive distributed lag (ADL) model (also known as the Koyck lag). One advantage of the multivariate ARIMA model is that "common, abrupt changes in the levels of the time series do not distort the seasonal patterns generated by the seasonal adjustment model" (Greenaway-McGrevy, 2013). The enhanced first-order ADL model is suitable to perform the Koyck transformation in order to reduce the number of explanatory variables. A detailed description of the low-frequency macroeconometric model is provided in Section 1.3.

The main results of this essay are summarized as follows. First, trade and average hourly compensation costs have a positive, statistically significant impact on FDI net inflows in Singapore. Second, higher levels of human capital per person exert a positive, statistically significant influence on gross fixed capital formation and labor compensation in Singapore. Third, real effective exchange rate, which reflects the real value of the Singapore dollar (SGD) against a weighted average of the currencies of Singapore's major trading partners, is positively associated with openness to trade, unit labor costs, and real interest rate in Singapore. Fourth, inflation as measured by the annual growth rate of the GDP implicit deflator has a negative, statistically significant effect on domestic credit to private sector in Singapore, while value added ratio of services, etc. defined as the ratio of value added in services, etc. to value added in manufacturing has a positive, statistically significant effect. Fifth, capital stock in Singapore exhibits a positive and statistically significant correlation with gross fixed capital formation, and a negative and not statistically significant correlation with FDI net inflows. My results are broadly consistent with evidence from previous empirical studies, and have important policy implications for characterizing Singapore's medium- and long-term growth path.

The remainder of this essay is organized as follows. Section 1.2 provides a brief literature review of major macroeconometric models of the Singaporean economy. Section 1.3 describes the Singapore low-frequency model consisting of the multivariate ARIMA model and the enhanced first-order ADL model presented in Subsections 1.3.1 and 1.3.2, respectively. Section 1.4 introduces data in Subsection 1.4.1 and estimation methods for the two submodels in Subsections 1.4.2 and 1.4.3, respectively. Section 1.5 reports results and policy implications. Section 1.6 provides concluding remarks.

1.2 Literature Review

There are three major macroeconometric models of the Singaporean economy: the MMS, the SMS, and the ESU01 model. The first two models are developed and maintained by the Monetary Authority of Singapore (MAS) as Singapore's central bank. The ESU01 model, as the first macroeconometric model of the Singaporean economy released to the public in its complete form, is initially constructed by Abeysinghe and Choy between 2001 and 2005, and currently comes under the Singapore Center for Applied and Policy Economics (SCAPE).

The MMS is essentially a macro-computable general equilibrium model based on the optimizing behavior of economic agents. It analyzes the dynamic effects of policies at national and sectoral levels using information about production activities in Singapore, which is obtained from the input-output tables. The MMS consists of 353 equations that are classified into three categories: 47 behavioral equations, 28 supplementary equations, and 278 identity equations. Both short- and long-term dynamics are captured, considering the behavioral equations are estimated using the error-correction models. Based on the optimizing behavior of households, firms, and the government, the model takes into account the demand and supply side of the economy and has a detailed sectoral breakdown. For example, the behavioral equations cover a broad range of economic activities: households, businesses, world trade markets, policy reaction equations, financial market behavioral identities, and other equations.

The SMS is essentially a set of New Keynesian dynamic stochastic general equilibrium (DSGE) models in the framework of imperfect competition and rational expectations. It consists of three core behavioral equations: an aggregate demand or output gap equation, a price-setting or New Keynesian Phillips curve equation, and a monetary policy equation. Under the assumption of price rigidity in the short run, the model highlights the stabilizing role of policy, especially monetary policy. For example, the model simulates the impact of shocks on the Singaporean economy, and combines the simulation results with the MMS's results to determine monetary policy. The SMS focuses on the deviation of key macroeconomic variables, such as aggregate demand and inflation, from their equilibrium levels, and is suitable for small-data-set economic forecasting in particular. A noteworthy feature of the model is that it follows Bayesian estimation procedures that emphasize structural changes in the Singaporean economy rather than the goodness of fit of the model.

Abeysinghe and Choy (2007) provide a complete documentation of the ESU01 model for structural analysis and forecasting. As the first macroeconometric model of the Singaporean economy released to the public in its complete form, the ESU01 model consists of 62 equations (36 behavioral equations and 26 identity equations) that are grouped into four blocks: trade block, sectoral block, labor market block, and domestic demand block. The impact of an external shock is transmitted from the expenditure-based trade block to the rest of the Singaporean economy through domestic demand block, then through sectoral and labor market blocks. The ESU01 model is demand-driven in the short run, and emphasizes cointegration relationships and short-term dynamics drawing upon the input-output tables. It tests cointegration restrictions instead of explicit steady-state restrictions, which are long-term equilibrium relationships themselves. The results of the ESU01 model can be used for ex ante forecasting and policy simulation at disaggregated levels as well.

Klein and Kushnirsky (2005) develop a variety of techniques for constructing and combining macroeconometric models at different frequencies in an economy. The results of a low-frequency macroeconometric model present the relationship between macroeconomic variables. Moreover, they can be combined with that of a high-frequency macroeconometric model to improve the accuracy of medium-term forecasting of real output. Klein et al. (2008) and Klein et al. (2012) construct two low-frequency macroeconometric models to carry out event and policy analysis in Mexico and Ukraine. Both models consist of a collection of structural equations to examine the association between macroeconomic variables in each economy. To my knowledge, this is the first study that applies the techniques for the low-frequency macroeconometric model developed by Klein et al. (2008) and Klein et al. (2012) to the Singaporean economy. A detailed description of the Singapore low-frequency model, which contains the multivariate ARIMA model and the enhanced first-order ADL model, is provided in Section 1.3.

1.3 The Singapore Low-Frequency Model

1.3.1 The Multivariate ARIMA Model

The multivariate ARIMA model shows the relationship between the dependent variable and other regressors besides lagged dependent variables up to the lag length p and forecast errors up to the lag length q. In general, the multivariate ARIMA model identifies the orders of autoregressive, differencing, and moving average processes using autocorrelation function (ACF) and partial autocorrelation function (PACF) plots. If ACF dies out geometrically and PACF reduces to zero rapidly at lag p, the corresponding time series follows an AR(p) process. If PACF dies out geometrically and ACF reduces to zero rapidly at lag q, the corresponding time series follows a MA(q) process. The corresponding time series is integrated of order d, or I(d), if it becomes covariance stationary[4] after differencing d times.

[4] A time series is covariance stationary if its statistical properties (e.g., mean and variance) neither change over time nor follow any trends.

In summary, the multivariate ARIMA model of AR(p), I(d), and MA(q) with n other regressors in period t, $x_{i,t}$ (i = 1, 2, ..., n) has the form

$$\Delta y_t = \delta + \rho_1 \Delta y_{t-1} + \rho_2 \Delta y_{t-2} + \ldots + \rho_p \Delta y_{t-p} + \lambda_1 \Delta x_{1,t} + \lambda_2 \Delta x_{2,t} + \ldots + \lambda_n \Delta x_{n,t} + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \ldots + \theta_q \varepsilon_{t-q} \quad (1.3.1.1)$$

where Δy_t and $\Delta x_{i,t}$ are the stationary states of y_t and $x_{i,t}$ with dth-order differencing, respectively[5].

The multivariate ARIMA model can also be written as

$$y_t = \mu + \sum_{n=1}^{t} \frac{w_n(B)}{\delta_n(B)} B^{k_n} x_{n,t} + \frac{\theta(B)}{\phi(B)} a_t \quad (1.3.1.2)$$

where

y_t: the dependent variable in period t

μ: a constant term

$x_{n,t}$: the nth regressor in period t

B: the lag operator (e.g., $y_{t-1} = By_t$)

$w_n(B)$: the numerator polynomial of the transfer function for the nth regressor

$\delta_n(B)$: the denominator polynomial of the transfer function for the nth regressor

[5] If y_t is stationary itself, the time series requires no further differencing (i.e., $\Delta y_t = y_t$).

k_n: the pure time delay for the effect of the *n*th regressor

$\phi(B)$: the autoregressive operator using a polynomial in the lag operator (e.g., $\phi(B) = 1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_p B^p$)

$\theta(B)$: the moving average operator using a polynomial in the lag operator (e.g., $\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q$)

a_t: the forecast error in period t

Equation (1.3.1.2) can be expressed in a simple form

$$y_t = \mu + \sum_{n=1}^{t} \psi_n(B) x_{n,t} + e_t \qquad (1.3.1.3)$$

where

$\psi_n(B)$: the transfer function for the *n*th regressor (i.e., $\psi_n(B) = \frac{w_n(B)}{\delta_n(B)} B^{k_n}$)

e_t: the white noise in period t (i.e., $e_t = \frac{\theta(B)}{\phi(B)} a_t$)

1.3.2 The Enhanced First-Order ADL Model

Following Koyck (1954), I construct the enhanced first-order ADL model to examine and compare the effects of gross fixed capital formation and FDI net inflows on capital stock in Singapore. According to the WDI 2014, gross fixed capital formation (formerly gross domestic fixed investment) refers to acquisitions less disposals of tangible and intangible fixed assets plus major improvements and costs of ownership transfer on land and other non-produced assets. It includes land improvements; plant, machinery, and equipment purchases; the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings; and net acquisitions of valuables. As one of the four components of the expenditure approach, gross fixed capital formation is a measure of net investment that equals gross investment less depreciation. It provides a more accurate estimation of net additions to capital stock, since repairs and replacements from increased capital stock are deducted.

According to the WDI 2014, FDI net inflows are the net inflows of investment (new investment less disinvestment) to acquire a lasting management interest (10 percent or more of voting stock) in a domestic enterprise by foreign investor. They comprise equity capital, reinvestment of earnings, other long-term capital, and short-term capital recorded in the balance of payments. Previous studies have used FDI inflows as a percentage of gross fixed capital formation to examine the impact of foreign investment relative to domestic investment on capital accumulation and output growth (e.g., Desai et al., 2005; Alfaro et al., 2006). FDI, which contains equity capital, reinvested earnings, and intra-company loans, is used to cover a deficit or pay off a loan in a domestic enterprise. A high value of FDI inflows as a percentage of gross fixed capital formation may arise from foreign takeovers without net additions to capital stock. It is thus necessary to test whether FDI net inflows is a good measure of gross fixed capital formation for capital accumulation in Singapore.

The perpetual inventory method is used to estimate a country's capital stock accumulated from past gross fixed capital formation. The positive, lasting effect of gross fixed capital formation on capital stock is expected to diminish gradually, but never falls to zero. As a result, capital stock can be expressed as a weighted sum of net investments in all previous periods where recent net investments are weighted more heavily than distant net investments. The assumption of geometrically declining weights is practically valid with respect to depreciation and obsolescence, such as physical deterioration and functional obsolescence.

Now I can define the enhanced first-order ADL model as follows:

$$K_t = \delta_1 + \beta_1\left[\sum_{i=0}^{n}\left(\phi_1^i GFCF_{t-i}\right)\right] + u_t \tag{1.3.2.1}$$

$$K_t = \delta_2 + \beta_2\left[\sum_{i=0}^{n}\left(\phi_2^i FDI_{t-i}\right)\right] + u_t \tag{1.3.2.2}$$

where K_t is capital stock in period t, $GFCF_{t-i}$ is gross fixed capital formation in period t-i, FDI_{t-i} is FDI net inflows in period t-i, δ_1 and δ_2 are constant terms, β_1 and β_2 are scale factors, ϕ_1^i and ϕ_2^i are retention rates in period t-i, and u_t is the white noise in period t.

The dynamic marginal effects of $GFCF_{t-i}$ and FDI_{t-i} on expected capital stock in period t, $E(K_t)$, are

$$\frac{\partial \mathrm{E}(K_t)}{\partial GFCF_{t-i}} = \beta_1 \phi_1^i \quad (1.3.2.3)$$

$$\frac{\partial \mathrm{E}(K_t)}{\partial FDI_{t-i}} = \beta_2 \phi_2^i \quad (1.3.2.4)$$

The cumulative effects of $GFCF_{t-i}$ and FDI_{t-i} can be expressed as an infinite geometric series,

$$\beta_1\left(\sum_{i=0}^{n} \phi_1^i\right) = \frac{\beta 1}{1-\phi_1},\ \beta_1 > 0,\ |\phi_1| < 1 \quad (1.3.2.5)$$

$$\beta_2\left(\sum_{i=0}^{n} \phi_2^i\right) = \frac{\beta 2}{1-\phi_2},\ \beta_2 > 0,\ |\phi_2| < 1 \quad (1.3.2.6)$$

To reduce the number of explanatory variables, I perform the Koyck transformation by respectively multiplying the one-period-lagged Equations (1.3.2.1) and (1.3.2.2) by ϕ_1^i and ϕ_2^i such that

$$\phi_1 K_{t-1} = \phi_1 \delta_1 + \phi_1 \beta_1\left[\sum_{i=1}^{n+1}\left(\phi_1^{i-1} GFCF_{t-i}\right)\right] + \phi_1 u_{t-1} \quad (1.3.2.7)$$

$$\phi_2 K_{t-1} = \phi_2 \delta_2 + \phi_2 \beta_2\left[\sum_{i=1}^{n+1}\left(\phi_2^{i-1} FDI_{t-i}\right)\right] + \phi_2 u_{t-1} \quad (1.3.2.8)$$

Then I subtract Equations (1.3.2.7) and (1.3.2.8) from Equations (1.3.2.1) and (1.3.2.2), respectively, such that

$K_t - \phi_1 K_{t-1} = \delta_1 + \beta_1 \left[\sum_{i=0}^{n}\left(\phi_1^i GFCF_{t-i}\right)\right] + u_t - \phi_1 \delta_1 - \phi_1\beta_1\left[\sum_{i=1}^{n+1}\left(\phi_1^{i-1} GFCF_{t-i}\right)\right] - \phi_1 u_{t-1} = (1 - \phi_1)\delta_1 + \beta_1 GFCF_t + (u_t - \phi_1 u_{t-1})$ (1.3.2.9)

$K_t - \phi_2 K_{t-1} = \delta_2 + \beta_2\left[\sum_{i=0}^{n}\left(\phi_2^i FDI_{t-i}\right)\right] + u_t - \phi_2\delta_2 - \phi_2\beta_2\left[\sum_{i=1}^{n+1}\left(\phi_2^{i-1} FDI_{t-i}\right)\right] - \phi_2 u_{t-1} = (1 - \phi_2)\delta_2 + \beta_2 FDI_t + (u_t - \phi_2 u_{t-1})$ (1.3.2.10)

The general form of the enhanced first-order ADL model can be expressed as follows:

$$K_t = \eta_1 + \eta_2 K_{t-1} + \eta_3 GFCF_t + v_t \quad (1.3.2.11)$$

$$K_t = \theta_1 + \theta_2 K_{t-1} + \theta_3 FDI_t + \tau_t \quad (1.3.2.12)$$

where $\eta_1 = (1 - \phi_1)\delta_1$, $\eta_2 = \phi_1$, $\eta_3 = \beta_1$, $v_t = u_t - \phi_1 u_{t-1}$, $\theta_1 = (1 - \phi_2)\delta_2$, $\theta_2 = \phi_2$, $\theta_3 = \beta_2$, and $\tau_t = u_t - \phi_2 u_{t-1}$.

The explanatory variable K_{t-1} is correlated with the error terms v_t and τ_t in Equations (1.3.2.11) and (1.3.2.12), which suggests that the problem of endogeneity exists as K_{t-1} depends on the error term u_{t-1} in Equations (1.3.2.7) and (1.3.2.8). As a violation of the Gauss-Markov assumptions, endogeneity may arise from omitted-variable bias, simultaneity bias, or errors-in-variables bias. Instrumental variables (IV) regression is used to eliminate bias and control for unobserved heterogeneity. A more detailed description of estimation methods for correcting for endogeneity is provided in Subsection 1.4.3.

1.4 Data and Estimation Methods

1.4.1 Data

The data come from the WDI 2014, the Penn World Table (PWT) version 8.0, the Singapore Department of Statistics (DOS), and the St. Louis Fed's Federal Reserve Economic Data (FRED). The WDI 2014 provides a large set of internationally comparable statistics in over 200 countries. The PWT version 8.0 is a database of income, output, input, and productivity that covers 167 countries. The Singapore DOS collects, compiles, and disseminates official economic data to analyze economic trends and develop economic projections. The St. Louis Fed's FRED is a database that has over 247000 economic time series from 79 sources.

The Singapore low-frequency model with annual observations contains 22 variables (8 dependent variables and 14 explanatory variables) for which data are available over the period 1980-2009. A detailed description of these variables is presented in subsequent sections. All nominal variables denominated in the SGD are converted into real terms. Summary and descriptive statistics of variables in the Singapore low-frequency model are shown in Tables 1.1 and 1.2, respectively.

Table 1.1 Summary of Variables in the Singapore Low-Frequency Model

Variable	Description	Measurement Unit	Source
Ln(FDI)	FDI net inflows	Million SGD	WDI 2014
Ln(GFCF)	Gross fixed capital formation	Million SGD	WDI 2014
O	Openness to trade	Ratio	WDI 2014
Ln(LC)	Labor compensation	Million SGD	PWT 8.0
ULC	Unit labor costs (2005=100)	Index	Singapore DOS
Ln(CP)	Domestic credit to private sector	Million SGD	WDI 2014
RIR	Real interest rate	Percentage	WDI 2014
Ln(K)	Capital stock	Million SGD	PWT 8.0
Ln(T)	Trade	Million SGD	WDI 2014
W	Average hourly compensation costs	SGD	WDI 2014, PWT 8.0
Ln(S)	Gross savings	Million SGD	WDI 2014
HCP	Human capital per person	Index	PWT 8.0
Ln(ECI)	Exports as a capacity to import	Million SGD	WDI 2014
REER	Real effective exchange rate (2010=100)	Index	WDI 2014
Ln(Y)	GDP	Million SGD	WDI 2014
PROD	Labor productivity	SGD	WDI 2014, FRED
INF	Inflation	Percentage	WDI 2014
SI	Value added ratio of services, etc.	Ratio	WDI 2014
IRS	Interest rate spread	Percentage	WDI 2014
Ln(K_1)	One-Period-Lagged capital stock	Million SGD	PWT 8.0

Table 1.2 Descriptive Statistics of Variables in the Singapore Low-Frequency Model

Variable	Min	Max	Mean	SD
Ln(FDI)	8.14	11.20	9.51	0.87
Ln(GFCF)	9.53	11.27	10.47	0.52
O	2.95	4.40	3.55	0.40
Ln(LC)	9.78	11.76	10.89	0.59
ULC	63.33	112.04	95.15	13.58
Ln(CP)	10.32	12.53	11.58	0.67
RIR	-0.50	10.09	4.66	3.02
Ln(K)	12.09	14.16	13.24	0.62
Ln(T)	12.10	14.03	12.96	0.64
W	6.08	18.60	13.23	3.97
Ln(S)	9.55	11.82	10.87	0.66
HCP	1.94	2.74	2.37	0.25
Ln(ECI)	10.50	13.29	11.96	0.91
REER	83.21	109.07	97.25	7.07
Ln(Y)	10.69	12.55	11.70	0.58
PROD	15.13	43.88	29.76	8.90
INF	-3.90	11.22	2.18	3.21
SI	2.90	3.90	3.50	0.24
IRS	-5.05	5.75	0.71	3.06
Ln(K_1)	11.99	14.10	13.17	0.64

1.4.2 Estimation Methods for the Multivariate ARIMA Model

Following the three-stage iterative approach[6] developed by Box et al. (2008), I analyze the multivariate ARIMA model by performing five tests. First, I take the natural log of the dependent and independent variables, which reduces heteroskedasticity and multicollinearity, produces stationary time series, and normalizes the data. I perform the

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[6] The three stages are identification, estimation, and diagnostic checking.

Breusch-Pagan test for conditional heteroskedasticity under the null hypothesis of homoscedasticity. The coefficients of natural-log transformed variables in a log-log regression are interpreted as elasticities.

Second, I perform the ADF test for a unit root to avoid the problem of spurious regression that results in misleading causal relationships. The null hypothesis of this test is that there is a unit root (difference-stationary), against the alternative hypothesis that there is no unit root (trend-stationary). The model allows higher-order autoregressive and moving average processes in addition to simple first-order processes. The optimal lag length is determined by the Akaike information criterion (AIC). Note that all variables must be integrated to the same order to form a cointegrating relationship, and make the residual series be a stationary stochastic process.

Third, I test for serial correlation in the error terms using the Breusch-Godfrey test. Serial correlation, as a violation of the assumptions underlying ordinary least squares (OLS) estimation, leads to biased and inconsistent OLS estimators. The Breusch-Godfrey serial correlation test allows higher-order autoregressive and moving average processes. Additionally, it is not restricted to the assumption of strict exogeneity. If the p-value is less than the chosen significance level, the null hypothesis of no serial correlation up to a specified lag length is rejected.

Fourth, I perform the unrestricted cointegration rank test to examine whether there exists a long-term relationship between variables. This vector autoregression (VAR)-based test is essentially the maximum likelihood estimation of reduced-rank regression models. Consider a VAR with *p* lags, VAR(*p*),

$$y_t = \sum_{i=1}^{P} A_i y_{t-i} + Bx_t + \varepsilon_t \qquad (1.4.2.1)$$

where y_t is an n × 1 vector of non-stationary variables, x_t is an n × 1 vector of deterministic variables, and ε_t is an n × 1 vector of innovations.

Equation (1.4.2.1) can also be written as

$$\Delta y_t = \prod y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + Bx_t + \varepsilon_t \qquad (1.4.2.2)$$

in which

$$\prod = \sum_{i=1}^{p} A_i - I, \ \Gamma_i = -\sum_{j=i+1}^{p} A_j \qquad (1.4.2.3)$$

If the reduced rank of the coefficient matrix $\prod$, r, is less than n, the n × r matrices α and β have the same rank as the coefficient matrix $\prod$ such that $\prod = \alpha\beta'$ (Granger, 1983; Engle and Granger, 1987). The Johansen’s trace test is designed to estimate $\prod$ in an unrestricted form and then test the significance of the r largest canonical correlations of Δy_t with y_{t-1}. If the MacKinnon-Haug-Michelis (1999) p-value is less than the chosen asymptotic critical value, the null hypothesis of r cointegrating vectors against the alternative hypothesis of n cointegrating vectors is rejected.

Fifth, I perform the pairwise Granger causality test to examine whether lags of one variable help predict another variable with its own lags in a bivariate linear regression. Consider a bivariate linear regression with the optimal lag length *p*,

$$y_t = \mu_1 + \sum_{i=1}^{p} \alpha_i y_{t-i} + \sum_{i=1}^{p} \beta_i x_{t-i} + \varepsilon_{1,t} \qquad (1.4.2.4)$$

$$x_t = \mu_2 + \sum_{i=1}^{p} \gamma_i x_{t-i} + \sum_{i=1}^{p} \delta_i y_{t-i} + \varepsilon_{2,t} \qquad (1.4.2.5)$$

The joint null hypothesis of the pairwise Granger causality test is

$$H_0^{11} : \beta_1 = \beta_2 = \cdots = \beta_P = 0 \text{ and } H_0^{12} : \delta_1 = \delta_2 = \cdots = \delta_P = 0 \qquad (1.4.2.6)$$

which indicates that the independent variable x_{t-i} does not Granger-cause the dependent variable y_t in Equation (1.4.2.4), and the independent variable y_{t-i} does not Granger-cause the dependent variable x_t in Equation (1.4.2.5). The Wald-test statistics are used to test the joint null hypothesis, as it is suitable for a small-sample-size model, such as the multivariate ARIMA model in this essay. A rule of thumb is that the independent variable Granger-causes the dependent variable, not the other way round.

1.4.3 Estimation Methods for the Enhanced First-Order ADL Model

As indicated in Subsection 1.3.2, the problem of endogeneity in the enhanced first-order ADL model arises from the correlation between the one-period-lagged capital stock K_{t-1} as a regressor and the error terms v_t and τ_t in Equations (1.3.2.11) and (1.3.2.12). IV regression uses at least one instrument to isolate the movements in the endogenous regressor that are uncorrelated with the error term. If the number of instruments is greater than the number of endogenous regressors, the IV estimator is defined as over-identified. If the number of instruments equals the number of endogenous regressors, the IV estimator is defined as just-identified.

A valid instrument should satisfy two conditions. First, it is highly correlated with the endogenous regressor even after controlling for endogeneity (i.e., instrument relevance). This condition can be tested in the first-stage regression of two-stage least squares (2SLS) regression. Nevertheless, 2SLS regression may perform poorer than OLS regression if instruments are weak (Stock and Yogo, 2002). The test for weak instruments compares the first-stage F-statistic with the chosen critical value if there is only one endogenous regressor. It compares the Cragg-Donald Wald F-statistic with the chosen critical value if there are multiple endogenous regressors. A rule of thumb is that an instrument is not weak if the first-stage F-statistic exceeds 10.

Second, a valid instrument is uncorrelated with the error term (i.e., instrument exogeneity). This condition requires strong theoretical argument and the application of knowledge for practical purposes. Tests of over-identifying restrictions, such as the J-test, are used if the number of instruments, m, is greater than the number of endogenous regressors, k. Let F denote the homoscedasticity-only F-statistic. The J-statistic, J, equals the number of instruments multiplying the homoscedasticity-only F-statistic (J = mF). The J-test examines the null hypothesis, indicating that all instruments are exogenous, against the alternative hypothesis, indicating that at least one of them is not exogenous. A rejection of the null hypothesis implies that the instruments are either not truly exogenous, or incorrectly excluded from the regression (i.e., omitted-variable bias). Following Klein et al. (2008)[7], the one-period-lagged gross fixed capital formation, $GFCF_{t-1}$, and the one-period-lagged FDI net inflows, FDI_{t-1}, are instruments for the one-period-lagged capital stock K_{t-1} as a regressor.

1.5 Results

Tables 1.3-1.7 report the test results of the multivariate ARIMA model. As shown in Table 1.3, the results of the Breusch-Pagan test for conditional heteroscedasticity indicate that the null hypothesis of homoscedasticity is not rejected at the 0.05 significance level. The results of the ADF test for a unit root show that time series become stationary after first differencing in Table 1.4. As shown in Table 1.5, the results of the Breusch-Godfrey serial correlation test indicate that the null hypothesis of no serial correlation up to a specified lag length p (p = 1 or 2) is not rejected at the 0.05 significance level. The results of the unrestricted cointegration rank test show that the null hypothesis of no cointegration is rejected at the 0.05 significance level in Table 1.6. As shown in Table 1.7,

[7] Klein et al. (2008) use the one-period-lagged investment as the instrument for the endogenous regressor of the one-period-lagged capital stock to estimate the influence of investment on capital stock in Mexico.

the results of the pairwise Granger causality test indicate that the explanatory variables help predict the dependent variables in all bivariate linear regressions.

Table 1.3 The Results of the Breusch-Pagan Test for Conditional Heteroskedasticity

Dependent Variable	Obs*R-squared	Prob. Chi-square	Degree of Freedom (DF)	Heteroskedasticity
Ln(FDI)	1.71**	0.43	2	No
Ln(GFCF)	0.03**	0.98	2	No
O	1.42**	0.49	2	No
Ln(LC)	0.17**	0.92	2	No
ULC	0.49**	0.78	2	No
Ln(CP)	3.56**	0.31	3	No
RIR	0.92**	0.63	2	No

Note: ** means that the null hypothesis of homoscedasticity is not rejected at the 0.05 significance level.

Table 1.4 The Results of the ADF Test for a Unit Root in Levels and First Differences

Variable	t-statistic (levels)	Prob. (levels)	t-statistic (first differences)	Prob. (first differences)	Conclusion
Ln(FDI)	-3.37*	0.08	-5.48***	0.00	I(1)
Ln(GFCF)	-1.09	0.70	-2.88*	0.06	I(1)
O	-3.41*	0.07	-4.24**	0.01	I(1)
Ln(LC)	-0.97	0.75	-2.92*	0.06	I(1)
ULC	-2.33	0.40	-3.63**	0.05	I(1)
Ln(CP)	-4.02**	0.02	-4.69***	0.00	I(1)
RIR	-1.18	0.21	-2.67**	0.01	I(1)
Ln(T)	-0.37	0.90	-3.74***	0.01	I(1)
W	-2.00	0.28	-3.17**	0.03	I(1)
Ln(S)	-2.52	0.32	-3.80**	0.03	I(1)
HCP	-4.71***	0.01	-4.81***	0.01	I(1)
Ln(ECI)	-1.78	0.69	-3.45*	0.07	I(1)
REER	-0.44*	0.51	-3.40***	0.00	I(1)
Ln(Y)	-1.11	0.91	-3.89**	0.03	I(1)
PROD	0.91**	0.90	-2.48**	0.02	I(1)
INF	-1.39	0.15	-2.12**	0.04	I(1)
SI	0.57	0.83	-3.96***	0.00	I(1)
IRS	-4.37***	0.00	-2.08**	0.04	I(1)

Note: ***, **, and * stands for the 0.01, 0.05, and 0.10 significance level at which the null hypothesis of a unit root (difference-stationary) is rejected, respectively. Prob. denote MacKinnon (1996) one-sided p-values.

Table 1.5 The Results of the Breusch-Godfrey Serial Correlation Test

Dependent Variable	Obs*R-squared	Prob. Chi-square	Lag Length	Autocorrelation
Ln(FDI)	0.45**	0.80	2	No
Ln(GFCF)	0.09**	0.76	1	No
O	0.00**	1.00	1	No
Ln(LC)	0.09**	0.77	1	No
ULC	0.23**	0.63	1	No
Ln(CP)	0.17**	0.68	1	No
RIR	2.15**	0.14	1	No

Note: ** means that the null hypothesis of no serial correlation up to a specified lag length p (p = 1 or 2) is not rejected at the 0.05 significance level.

Table 1.6 The Results of the Unrestricted Cointegration Rank Test

Variable	Hypothesized # of Cointegration Eqn(s) (CE(s))	Trace Statistic	5% Critical Value	Prob.	# of CE(s)
Ln(FDI), Ln(T), and W	None*	36.62	29.80	0.01	1
	At most 1	10.16	15.49	0.27	
	At most 2	2.23	3.84	0.14	
Ln(GFCF), Ln(S), and HCP	None*	52.81	29.80	0.00	1
	At most 1	15.04	15.49	0.06	
	At most 2*	4.91	3.84	0.03	
O, Ln(ECI), and REER	None*	34.66	29.80	0.01	1
	At most 1	12.54	15.49	0.13	
	At most 2*	4.92	3.84	0.03	
Ln(LC), HCP, and Ln(Y)	None*	56.27	29.80	0.00	3
	At most 1*	26.91	15.49	0.00	
	At most 2*	6.40	3.84	0.01	
ULC, REER, and PROD	None*	33.31	29.80	0.02	3
	At most 1*	17.59	15.49	0.02	
	At most 2*	7.07	3.84	0.01	
Ln(CP), Ln(Y), INF, and SI	None*	75.00	47.86	0.00	2
	At most 1*	33.89	29.80	0.02	
	At most 2	5.68	15.49	0.73	
	At most 3	1.64	3.84	0.20	
RIR, REER, and IRS	None*	46.39	29.80	0.00	3
	At most 1*	18.04	15.49	0.02	
	At most 2*	5.86	3.84	0.02	

Note: * means that the null hypothesis of no cointegration is rejected at the 0.05 significance level. Prob. denote MacKinnon (1996) one-sided p-values.

Table 1.7 The Results of the Pairwise Granger Causality Test

Variable	Null Hypothesis	Obs	F-statistic	Prob.	Lag Length	Conclusion
Ln(FDI), Ln(T), and W	T does not Granger cause FDI	29	13.59	0.00	1	T Granger causes FDI
	FDI does not Granger cause T		2.78	0.11		W Granger causes FDI
	W does not Granger cause FDI		12.45	0.00		
	FDI does not Granger cause W		1.00	0.33		
Ln(GFCF), Ln(S), and HCP	S does not Granger cause GFCF	28	5.91	0.01	2	S Granger causes GFCF
	GFCF does not Granger cause S		0.50	0.61		HCP Granger causes GFCF
	HCP does not Granger cause GFCF		7.47	0.00		
	GFCF does not Granger cause HCP		0.22	0.80		
O, Ln(ECI), and REER	ECI does not Granger cause O	27	1.91	0.05	3	ECI Granger causes O
	O does not Granger cause ECI		1.05	0.39		REER Granger causes O
	REER does not Granger cause O		3.75	0.03		
	O does not Granger cause REER		0.17	0.91		
Ln(LC), HCP, and Ln(Y)	HCP does not Granger cause LC	27	5.70	0.01	3	HCP Granger causes LC
	LC does not Granger cause HCP		0.32	0.81		Y Granger causes LC
	Y does not Granger cause LC		11.96	0.00		
	LC does not Granger cause Y		2.23	0.12		
ULC, REER, and PROD	REER does not Granger cause ULC	28	7.08	0.00	2	REER Granger causes ULC
			0.08	0.92		

	ULC does not Granger cause REER		4.17	0.03		PROD Granger causes ULC
	PROD does not Granger cause ULC		1.82	0.18		
	ULC does not Granger cause PROD					
Ln(CP), Ln(Y), INF, and SI	Y does not Granger cause CP	29	18.82	0.00	1	Y Granger causes CP
	CP does not Granger cause Y		2.21	0.15		INF Granger causes CP
	INF does not Granger cause CP		26.51	0.00		SI Granger causes CP
	CP does not Granger cause INF		0.83	0.37		
	SI does not Granger cause CP		15.66	0.00		
	CP does not Granger cause SI		1.60	0.22		
RIR, REER, and IRS	REER does not Granger cause RIR	28	9.66	0.00	2	REER Granger causes RIR
	RIR does not Granger cause REER		2.98	0.07		IRS Granger causes RIR
	IRS does not Granger cause RIR		3.37	0.05		
	RIR does not Granger cause IRS		0.98	0.39		

Table 1.8 presents the results of the multivariate ARIMA regression analysis. Regression (1) shows that trade and average hourly compensation costs have a positive, statistically significant impact on FDI net inflows in Singapore. A one percent increase in trade is associated with a 0.63 percent increase in FDI net inflows. Unlike the findings in the factor proportions framework (e.g., Mundell, 1957), the positive coefficient implies

that trade and FDI net inflows are complements rather than substitutes in Singapore. This finding is consistent with some previous studies that relax the assumptions of the Heckscher-Ohlin model (e.g., Markusen, 1983). FDI net inflows tend to promote trade if they are conducted in export-intensive industries, while reduce trade if they are conducted in import-competing industries. The complementary relationship between trade and FDI net inflows implies that export-intensive industries absorb more FDI net inflows than import-competing industries in Singapore. A one SGD increase in average hourly compensation costs is associated with a 10 percent increase in FDI net inflows. FDI net inflows into unskilled-labor-intensive industries may decline due to an increase in average hourly compensation costs, which makes labor more costly than other inputs in the host country or than labor in other countries. However, an increasing demand for skilled labor will raise the average hourly compensation costs of skilled labor relative to that of unskilled labor. The higher ratio of skilled labor to the total labor force in Singapore has formed a comparative advantage to attract FDI net inflows in recent years. This result can be explained by between-industry shifts in employment (Berman et al., 1994) and within-industry changes in wage share (Feenstra and Hanson, 1997).

Regression (2) shows that gross savings and human capital per person exert positive, statistically significant influences on gross fixed capital formation in Singapore. A one percent increase in gross savings is associated with a 0.50 percent increase in gross fixed capital formation. The flow of gross savings is the main source of financing acquisitions less disposals of non-financial assets including gross fixed capital formation. The self-financing ratio of gross savings to gross fixed capital formation measures how dependent an economy on foreign capital. The lower the ratio, the more dependent is the economy on foreign capital. Singapore is capable of financing gross fixed capital formation using its own resources, considering its similar sizes of gross savings and gross fixed capital formation. The indirect effects of human capital on gross fixed capital formation have not reached any clear conclusions in the literature. On the one hand, human capital accumulation helps acquire, absorb, and adapt new technologies. If new technologies are linked to gross fixed capital formation, human capital and gross fixed capital formation are positively associated (Barro, 1991; Krueger and Lindahl, 2001). On the other hand, human capital accumulation can partly offset the impact of decreasing returns to physical capital accumulation. Given the relatively constant ratio of physical capital to human capital in the long-run equilibrium, higher levels of human capital will result in higher levels of physical capital toward equilibrium (Barro and Sala-i-Martin, 1997; Barro, 2001). The positive relationship between human capital and gross fixed capital formation depends on the level of economic development as well (Duffy et al., 2004).

Regression (3) shows that exports as a capacity to import and real effective exchange rate have different effects on openness to trade in Singapore. Exports as a capacity to import has a positive, statistically significant impact on openness to trade as expected. It is defined as “the current price value of exports of goods and services deflated by the import price index” according to the WDI 2014. A decrease in exports as a capacity to import means that a country has to obtain a smaller volume of imports from the same amount of exports, that is, a deterioration in terms of trade of the country. Singapore is one of the few countries in the world that has highest levels of exports as a capacity to import.

The Singapore government has regularly adjusted investment patterns in export-intensive industries, and reduced trade costs in import-competing industries over the past few decades. Such structural adjustment and industrial upgrading are likely to promote higher levels of openness to trade (Razin et al., 2003). Real effective exchange rate, which reflects the real value of the Singapore dollar (SGD) against a weighted average of the currencies of Singapore's major trading partners, is positively associated with openness to trade. A decrease in real effective exchange rate means that the SGD depreciates relative to foreign currencies. Empirical researches have shown that a weaker home currency is often correlated with higher levels of openness to trade, and leads to a larger increase in trade and current account balances (Romelli et al., 2014). The weak, negative impact of real effective exchange rate on openness to trade in Singapore can be explained by the MAS's policy of a modest and gradual appreciation path of the SGD since 1981.

Regression (4) shows that human capital per person and GDP exert a positive, statistically significant influence on labor compensation in Singapore. According to the Labour Force Survey 2010 released by the Singapore Ministry of Manpower, labor compensation in Singapore consists of salaries, allowances, overtime, commission, tips, bonuses, and employee's social security savings. Singapore has experienced a rise in the service sector and a rapid skill acquisition since the 1990s. An increase in the supply of skilled workers expands the wage gap between skilled and unskilled workers, and leads to a greater proportion of skilled workers (Kiley, 1999; Buera and Kaboski, 2012). An alternative method of accounting for the positive impact of human capital is to decompose labor compensation into a component due to "raw labor" and a component due to human capital based on education and experience. For example, human capital compensation is estimated to be fifteen times greater than “raw labor” compensation in the U.S. (Krueger, 1999). A one percent increase in GDP is associated with a 0.86 percent increase in labor compensation. This result implies that Singapore’s labor compensation growth follows a procyclical pattern, and is consistent with empirical evidence obtained from the PWT version 8.0. Labor compensation rises during recoveries due to hiring lags and delays at early stages of the hiring process, and falls during recessions as enterprises are likely to reduce workers’ compensation costs instead of reducing their workforce.

Regression (5) shows that real effective exchange rate and labor productivity have positive, statistically significant effects on unit labor costs in Singapore. Unit labor costs are calculated as the ratio of labor costs to real output. The relative costs of non-tradable inputs (e.g., labor) are less equalized internationally in comparison with that of tradable inputs (e.g., physical capital and energy) in general. Therefore, unit labor costs are used to assess a country’s cost competitiveness relative to other countries (Turner and Golub, 1997). They can be very volatile due to short-term fluctuations in exchange rates. The SGD has appreciated against the U.S. dollar over the past few decades, which may hamper Singapore’s competitiveness of labor costs in the long run. Labor productivity is defined as the amount of real output produced per labor hour. An increase in labor productivity can partly offset the impact of a rise in hourly labor compensation on unit labor costs. Wan and Ong (2002) find that Singapore’s hourly labor compensation has grown faster than unit labor costs and labor productivity since the 1990s.

Regression (6) shows that GDP, inflation, and value added ratio of services, etc. exert different effects on domestic credit to private sector in Singapore. According to the WDI 2014, domestic credit to private sector “refers to financial resources provided to the private sector by financial corporations, such as through loans, purchases of non-equity securities, and trade credits and other accounts receivable, that establish a claim for repayment”. A one percent increase in GDP is associated with a 0.95 percent increase in domestic credit to private sector, which suggests that domestic credit to private sector in Singapore is strongly procyclical. A rise in inflation measured by the annual growth rate of the GDP implicit deflator leads to a decrease in domestic credit to private sector. This is consistent with previous findings in low-inflation countries including Singapore (e.g., Boyd et al., 2001; Backe and Egert, 2006). Inflation reduces incentives to save and invest with a lower real return on domestic asset, and further lowers domestic credit to private sector. Value added ratio of services, etc. is calculated as the ratio of value added in services, etc. to value added in manufacturing. The service sector has been the key engine of Singapore’s economic growth by accounting for over 70% of total value added by 2013. For example, banking activity that accounts for half of the service sector’s value added in Singapore is mainly driven by growth in commercial and industrial loans.

Regression (7) shows that real effective exchange rate and the interest rate spread between Singapore and the U.S. have different effects on real interest rate in Singapore. The main goals of Singapore’s exchange-rate-centered monetary policy are price stability and exchange rate stability in a managed floating system. As indicated above, the MAS has maintained the policy of a modest and gradual appreciation path of the SGD since 1981.

As a result, real interest rate in Singapore fluctuates moderately within a relatively narrow range. This is consistent with the MAS's claim that Singapore's interest rates reflect market expectations for the appreciation of the SGD over time. The interest rate spread between Singapore and the U.S. exhibits a negative, statistically significant impact on real interest rate in Singapore. This is consistent with the fact that real interest rates in Singapore and the U.S. have been relatively stable over the past decades. According to the MAS, Singapore's interest rates are largely determined by interest rates in the U.S. at higher average levels and investor expectations for future movements in the SGD.

Table 1.8 The Results of the Multivariate ARIMA Regression Analysis

Regression	Adjusted R-squared	DW Statistic	F-statistic
(1) $\text{Ln(FDI)} = \underset{(42.93)}{0.63\text{Ln(T)}} + \underset{(7.16)}{0.10\text{W}} - 0.44\text{MA(2)}$	0.82	2.16	28148.94
(2) $\text{Ln(GFCF)} = \underset{(3.30)}{0.50\text{Ln(S)}} + \underset{(3.00)}{1.91\text{HCP}} + 0.93\text{AR(1)} + 0.34\text{MA(1)}$	0.98	1.99	363.52
(3) $\text{O} = \underset{(17.20)}{0.50\text{Ln(ECI)}} - \underset{(-7.31)}{0.03\text{REER}} + 0.73\text{AR(1)} - 0.93\text{MA(1)}$	0.81	1.78	14699.60
(4) $\text{Ln(LC)} = \underset{(3.77)}{0.35\text{HCP}} + \underset{(46.07)}{0.86\text{Ln(Y)}} + 0.96\text{MA(1)}$	0.99	2.05	399977.20
(5) $\text{ULC} = \underset{(13.26)}{0.57\text{REER}} + \underset{(9.84)}{1.33\text{PROD}} + 0.86\text{MA(1)}$	0.92	1.63	2772.25
(6) $\text{Ln(CP)} = \underset{(51.51)}{0.95\text{Ln(Y)}} - \underset{(-2.51)}{0.01\text{INF}} + 0.17\text{SI} + 0.89\text{AR(1)} + 0.09\text{MA(1)}$	0.99	1.99	5677.89
(7) $\text{RIR} = \underset{(13.43)}{0.05\text{REER}} - \underset{(-17.95)}{0.88\text{IRS}} + 0.94\text{MA(1)}$	0.87	1.44	233.54

Note: The coefficient restrictions are not rejected at the 0.05 significance level. The t-statistics are presented in the parentheses below the coefficient estimates. Constant terms are not reported here.

The results of the enhanced first-order ADL model are expressed as follows:

$$\text{Ln(K)} = \underset{(-7.47\text{E}-05)}{-32.52} + \underset{(32.91)}{0.87\text{Ln(K\_1)}} + \underset{(11.61)}{0.12\text{Ln(GFCF)}} + \text{AR(1)} \qquad (1.5.1)$$

$$\text{Ln(K)} = \underset{(1.07)}{0.27} + \underset{(37.65)}{1.00\text{Ln(K\_1)}} - \underset{(-1.21)}{0.02\text{Ln(FDI)}} + \text{AR}(1) \qquad (1.5.2)$$

where capital stock Ln(K) is the dependent variable, the one-period-lagged capital stock Ln(K_1) is the endogenous regressor, the one-period-lagged gross fixed capital formation Ln(GFCF_1) and the one-period-lagged FDI net inflows Ln(FDI_1) are the instruments for the endogenous regressor, and gross fixed capital formation Ln(GFCF) and FDI net inflows Ln(FDI) are the included exogenous regressors in each equation. The t-statistics are presented in parentheses below the coefficient estimates.

The validity of the coefficient estimates depends on the two conditions that the instruments must satisfy: instrument relevance and instrument exogeneity. The first-stage F-statistics equal 543.26 and 34.40 in Equations (1.5.1) and (1.5.2), respectively, which means that the instruments are not weak. The J-statistics equal 3.75 and 0.44 in Equations (1.5.1) and (1.5.2), respectively. They are less than the Chi-square critical value of 3.84 with one degree of freedom at the 0.05 significance level. The condition of instrument exogeneity is satisfied, since the null hypothesis that both instruments are exogenous is not rejected.

The results of the enhanced first-order ADL model are summarized as follows. First, the one-period-lagged capital stock exerts a positive, statistically significant effect on current capital stock. A one percent increase in gross fixed capital formation is associated with a 0.12 percent increase in capital stock. The varying composition of gross fixed capital formation reflects changes in the sources of capital stock in Singapore (e.g., Peebles and Wilson, 2002; Sng, 2010). For example, investment levels in construction and works and transport equipment are lower than 1970s levels, while investments in machinery and equipment have increased significantly since the 1990s.

Second, FDI net inflows has a weak, negative impact on capital stock relative to domestic investment. This is consistent with previous findings that FDI net inflows is not a good measure of gross fixed capital formation for capital accumulation (e.g., Leino and Ali-Yrkko, 2014). The result can be explained by the fact that a high value of FDI inflows as a percentage of gross fixed capital formation may arise from foreign takeovers without net additions to capital stock. Another reason is changes in the sectoral composition of FDI net inflows. For example, Amighini et al. (2015) find that FDI inflows related to productive activities are more likely to spur capital accumulation than FDI inflows related to trade-related activities. Alfaro and Charlton (2007) find that the effects of FDI inflows depending on objective qualitative industry characteristics including human capital intensity and financial dependence vary by sector. According to Foreign Equity Investment in Singapore 2013, the finance and insurance sector absorbed 43.1% of FDI inflows in Singapore. The manufacturing sector and the wholesale and retail trade sector absorbed 20.4% and 17.6%, respectively. On the whole, FDI net inflows is a poor proxy for gross fixed capital formation in accounting for capital accumulation in Singapore.

1.6 Conclusion

Understanding recent trends in macroeconomic variables and investigating the association between them are important to analyze and forecast economic growth in Singapore. Using the Singapore low-frequency model consisting of the multivariate ARIMA model and the enhanced first-order ADL model, I explore the relationship between eight key macroeconomic variables and a variety of relevant macroeconomic variables in Singapore for the period 1980-2009. My results are broadly consistent with evidence from previous empirical studies, and have important policy implications for characterizing Singapore's medium- and long-term growth path. For example, besides the three major macroeconometric models of the Singaporean economy developed and maintained by the MAS and the SCAPE, the International Monetary Fund (IMF) has constructed small quarterly projection models using four to five behavioral equations. The Singapore government has undertaken a series of structural reforms centered on a number of key macroeconomic variables discussed in this essay since 2005.

CHAPTER 2

HOW IMPORTANT ARE QUALITY-ADJUSTED HUMAN CAPITAL AND TIME-VARYING FACTOR SHARES FOR ECONOMIC GROWTH: A CASE STUDY OF SINGAPORE

2.1 Introduction

One of the most important developments in the literature on economic growth is the enhanced appreciation of the role of quality-adjusted human capital in measuring the contributions of tangible inputs, such as physical capital and labor, and intangible inputs, such as productivity, to output growth (e.g., Becker et al., 1990; Rebelo, 1992; Mulligan and Sala-i-Martin, 1993). As an input that complements physical capital at the firm, industry, and national levels, quality-adjusted human capital makes a greater contribution to output growth the larger the stock of physical capital and vice versa (Mincer, 1984). Economic projections that fail to separate changes in quality-adjusted human capital and productivity will lead to less reliable results as claimed by Jorgenson and Stiroh (2000).

Human capital and its accumulation have been widely examined in previous studies. For example, the annual rate of convergence to the steady state would have been higher than the observed value of 2 percent with a narrow definition of capital that excludes human capital (Solow, 1956). Extensions of the neoclassical growth model allow imbalances between human capital and physical capital. Mulligan and Sala-i-Martin (1993) find that a higher ratio of human capital to physical capital results in a higher growth rate of output and a higher ratio of physical capital investment to GDP. Other extensions allow international trade in goods and assets (e.g., Barro and Sala-i-Martin, 1992) and technology diffusion (e.g., Romer, 1990). They conclude that the accumulation of human capital is often financed by gross domestic savings, and that a country with more human capital is more likely to absorb, adapt, and apply foreign technologies.

Conventional wisdom holds that factor shares are constant in an aggregate production function. For example, Hall and Jones (1999) assume that capital shares and labor shares are equal to 1/3 and 2/3 across countries, respectively. Gollin (2002) claims that the aggregate labor share does not change with the level of economic development. However, some studies have shown that factor shares vary over time and across countries. For example, the estimates of capital shares in Singapore vary from 0.35 to 0.49 (e.g., Bosworth and Collins, 2003; Sarel, 1997; Senhadji, 2000). The assumption of time-varying factor shares has been supported by empirical evidence. For example, Solow (1957) estimates the income shares of physical capital ranging from 0.312 to 0.397 to measure the productivity residual. Hicklin et al. (1997) use different capital shares ranging from 0.25 to 0.50 to calculate productivity growth rates over time and across countries in the Association of Southeast Asian Nations (ASEAN) including Singapore. Young (1992) finds that the capital shares in Singapore fell from 0.553 to 0.468 between 1970 and 1990, which further justifies the assumption of time-varying factor shares in Singapore.

This essay re-estimates the contributions of various inputs to Singapore's output growth for the period 1980-2009. To address the impact of quality-adjusted human capital and time-varying factor shares on these contributions, I extend the translog production function approach developed by Jorgenson et al. (1987) by incorporating human-capital-adjusted labor and the assumption of time-varying shares of physical capital. Based on the natural logarithm transformation of the aggregate production function, output can be expressed as an exponential function of linear and quadratic terms of the natural log of inputs and time. The results show that a decline in capital deepening is partly offset by improvements in labor quality and procyclical productivity growth. They also imply that estimation of contributions of various inputs without considering quality-adjusted labor input is biased.

The remainder of this essay is organized as follows. Section 2.2 gives an overview of previous studies focusing on the role of quality-adjusted human capital and time-varying factor shares. Section 2.3 describes the enhanced translog production function approach. Section 2.4 introduces the data sources. Section 2.5 analyzes the results. Section 2.6 concludes.

2.2 Literature Review

The purpose of measuring the contribution of labor to output growth is not simply to compare changes in the number of workers, but changes in the amount of labor services in an economy (Jorgenson et al., 1987). Workers can have different amounts of human capital based on a number of factors, including innate ability, schooling, school quality and non-schooling investments, (on-the-job) training, and pre-labor market influences (e.g., Acemoglu and Autor, 2011; Caselli, 2005; Hanushek and Woessman, 2008). In this essay, workers are heterogeneous with respect to average years of schooling and the rate of return to investment in education. Skill heterogeneity implies that workers with different levels of human capital provide different amounts of labor services.

Improvements in human capital depend on average years of schooling and the rate of return to investment in education. Barro and Lee (1993) construct a panel data set on educational attainment at four levels in more than 100 countries at 5-year intervals for the period 1960-1985 to examine the relationship between human capital and economic growth. Although the quality of schooling affects the accumulation of human capital, average years of schooling is still one of the most useful measures of human capital (Inklaar and Timmer, 2013). The other factor that determines skill heterogeneity is the rate of return to investment in education. Psacharopoulos (1994) claims that the law of diminishing marginal returns to human capital is upheld, and so is the declining returns to education.

Factor shares are traditionally assumed to be constant as indicated above (e.g., Hall and Jones, 1999; Gollin, 2002). However, recent studies have shown that they are variable over time and across countries. For example, some non-reproducible factor shares (e.g., natural capital shares) decrease as a country's level of economic development is higher, and some reproducible factor shares (e.g., human capital shares) increase as a country's level of economic development is higher (e.g., Peretto and Seater, 2013; Sturgill, 2012; Zuleta, 2008). Factor shares can also vary with labor market conditions, such as the reservation wage, the ratio of searching firms to unemployed workers, and the firm productivity distribution (e.g., Mangin, 2014; Rios-Rull and Santaeulalia-Llopis, 2010). Additionally, a decrease in physical capital shares has been found in some developing countries (e.g., Van et al., 2010; Young, 1992).

2.3 The Enhanced Translog Production Function Approach

This section presents a variant of the translog production function approach developed by Jorgenson et al. (1987). My approach incorporates human-capital-adjusted labor and the assumption of time-varying shares of physical capital. Based on the natural logarithm transformation of the aggregate production function, output can be expressed as an exponential function of linear and quadratic terms of the natural log of inputs and time. The growth rate of productivity is defined as the growth rate of output less a weighted average of the growth rates of inputs. The weight corresponds to the share of each input in the total cost of production.

Consider the translog production function given as follows:

$$\ln Y = \exp[\alpha_0 + \alpha_K \ln K + \alpha_{L_H} \ln L_H + \alpha_T \cdot T + \frac{1}{2}\beta_{KK}(\ln K)^2 + \beta_{KL_H}(\ln K)(\ln L_H) + \beta_{KT}\ln K \cdot T + \frac{1}{2}\beta_{L_H L_H}(\ln L_H)^2 + \beta_{L_H T}\ln L_H \cdot T + \frac{1}{2}\beta_{TT} \cdot T^2] \quad (2.3.1)$$

where Y denotes output, K denotes physical capital, L_H denotes human-capital-adjusted labor, and T denotes time.

Unlike homogeneous labor, L, human-capital-adjusted labor, L_H, is defined as follows:

$$L_H = h \cdot L \tag{2.3.2}$$

where h denotes the index of human capital per person based on average years of schooling and the rate of return to investment in education. Time, T, captures changes in the level of productivity.

The value shares of physical capital, v_K, human-capital-adjusted labor, v_{L_H}, and productivity, v_T, estimated by the elasticities of output with respect to each of them are

$$v_K = \alpha_K + \beta_{KK} \ln K + \beta_{KL_H} \ln L_H + \beta_{KT} \cdot T \tag{2.3.3}$$

$$v_{L_H} = \alpha_{L_H} + \beta_{KL_H} \ln K + \beta_{L_H L_H} \ln L_H + \beta_{L_H T} \cdot T \tag{2.3.4}$$

$$v_T = \alpha_T + \beta_{KT} \ln K + \beta_{L_H T} \ln L_H + \beta_{TT} \cdot T \tag{2.3.5}$$

Under the assumption of constant returns to scale, the coefficients in Equation (2.3.1) satisfy the following conditions:

$$\alpha_K + \alpha_{L_H} = 1, \beta_{KK} + \beta_{KL_H} = 0, \beta_{KL_H} + \beta_{L_H L_H} = 0, \beta_{KT} + \beta_{L_H T} = 0 \tag{2.3.6}$$

The necessary conditions for the fact that the translog production function is increasing and concave in both inputs imply that

$$0 < \alpha_K \leq 1, 0 < \alpha_{L_H} \leq 1 \quad (2.3.7)$$

If there are m individual components of physical capital, the translog production function can be expressed as the following translog function of the individual components, K_i (i = 1, 2, ..., m):

$$K = \exp[\alpha_1 \ln K_1 + \alpha_2 \ln K_2 + ... + \alpha_m \ln K_m + \frac{1}{2}\beta_{11}(\ln K_1)^2 + \beta_{12}(\ln K_1)(\ln K_2) + ... + \beta_{1m}(\ln K_1)(\ln K_m) + ... + \frac{1}{2}\beta_{mm}(\ln K_m)^2] \quad (2.3.8)$$

Under the assumption of constant returns to scale, the share of the ith individual component of physical capital is

$$v_{K_i} = \alpha_i + \beta_{1i} \ln K_1 + ... + \beta_{im} \ln K_m \quad (2.3.9)$$

The growth rate of physical capital can be expressed as a weighted average of the growth rates of all individual components in the form

$$\ln K(T) - \ln K(T-1) = \sum \overline{v_{K_i}}[\ln K_i(T) - \ln K_i(T-1)] \quad (2.3.10)$$

where the weight, $\overline{v_{K_i}}$, is

$$\overline{v_{K_i}} = \frac{1}{2}[v_{K_i}(\mathrm{T}) + v_{K_i}(\mathrm{T}\text{-}1)] \qquad (2.3.11)$$

Similarly, if there are n individual components of human-capital-adjusted labor, the translog production function can be expressed as the following translog function of the individual components, L_{H_j} (j = 1, 2, ..., n):

$$L_H = \exp[\alpha_1 \ln L_{H_1} + \alpha_2 \ln L_{H_2} + ... + \alpha_n \ln L_{H_n} + \frac{1}{2}\beta_{11}(\ln L_{H_1})^2 + \beta_{12}(\ln L_{H_1})(\ln L_{H_2})$$
$$+ ... + \beta_{1n}(\ln L_{H_1})(\ln L_{H_n}) + ... + \frac{1}{2}\beta_{nn}(\ln L_{H_n})^2] \qquad (2.3.12)$$

Under the assumption of constant returns to scale, the share of the jth individual component of human-capital-adjusted labor is

$$v_{L_{H_j}} = \alpha_j + \beta_{1j}\ln L_{H_1} + ... + \beta_{jn}\ln L_{H_n} \qquad (2.3.13)$$

The growth rate of human-capital-adjusted labor can be expressed as a weighted average of the growth rates of all individual components in the form

$$\ln L_H(\mathrm{T}) - \ln L_H(\mathrm{T}\text{-}1) = \sum \overline{v_{L_{H_j}}}\left[\ln L_{H_j}(\mathrm{T}) - \ln L_{H_j}(\mathrm{T}-1)\right] \qquad (2.3.14)$$

where the weight, $\overline{v_{L_{H_j}}}$, is

$$\overline{v_{L_{H_j}}} = \frac{1}{2}[v_{L_{H_j}}(\mathrm{T}) + v_{L_{H_j}}(\mathrm{T-1})] \tag{2.3.15}$$

By first-differencing the logarithm of the translog production functions of physical capital and human-capital-adjusted labor above, I define the growth rate of output as follows:

$$\ln[\frac{\mathrm{Y(T)}}{\mathrm{Y(T-1)}}] = \overline{v_K}\ln[\frac{\mathrm{K(T)}}{\mathrm{K(T-1)}}] + \overline{v_{L_H}}\ln[\frac{L_H(\mathrm{T})}{L_H(\mathrm{T-1})}] + \overline{v_T} \tag{2.3.16}$$

where the weights are

$$\overline{v_K} = \frac{1}{2}[v_K(\mathrm{T}) + v_K(\mathrm{T-1})] \tag{2.3.17}$$

$$\overline{v_{L_H}} = \frac{1}{2}[v_{L_H}(\mathrm{T}) + v_{L_H}(\mathrm{T-1})] \tag{2.3.18}$$

$$\overline{v_T} = \frac{1}{2}[v_T(\mathrm{T}) + v_T(\mathrm{T-1})] \tag{2.3.19}$$

The average value share of productivity (also known as the translog index of productivity), $\overline{v_T}$, "provides a measure of the amount the log of output would have increased had all inputs remained constant between the two discrete time periods" (Young, 1992). Under the assumption of perfect competition, the elasticities of output with respect to physical capital and human-capital-adjusted labor equal their shares in total factor payments[8].

2.4 Data

The data used in this essay are taken from the WDI 2014, the PWT version 8.0, and the Bureau of Labor Statistics (BLS). The annual observations of output, physical capital, the index of human capital per person, and labor are collected for the period 1980-2009. Output growth can be decomposed into three components: physical capital growth, human-capital-adjusted labor growth, and productivity growth. As indicated above, the contribution of productivity growth to output growth depends on the elasticities of output with respect to physical capital and human-capital-adjusted labor.

Output, as measured by real GDP, is “the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products” according to the WDI 2014. The data on physical capital and the index of human capital per person come from the PWT version 8.0. As a Törnqvist aggregate of individual assets using the perpetual inventory method, capital stock at constant 2005 national prices is a measure of physical capital. The index of human capital

[8] The sum of the shares of physical capital and human-capital-adjusted labor equals one.

per person is calculated using average years of schooling and the rate of return to investment in education. The data on employment as a proxy for labor come from the BLS.

2.5 Results

In this section, I first present the benchmarking contributions of physical capital, labor, human-capital-adjusted labor, and productivity to output growth in Singapore using three constant capital shares of 0.49, 0.42, and 0.35 for the period 1980-2009, respectively. As indicated above, these shares are chosen based on existing literature (e.g., Bosworth and Collins, 2003; Sarel, 1997; Senhadji, 2000). Then I re-examine the contributions of inputs by assuming steadily declining capital shares ranging from 0.49 for the subperiod 1980-1986 to 0.35 for the subperiod 2004-2009 based on Young (1992).

Table 2.1 presents the absolute contributions of physical capital, labor, human-capital-adjusted labor, and productivity to output growth in Singapore using three constant capital shares of 0.49, 0.42, and 0.35 for the period 1980-2009, respectively. In general, physical capital contributes the most to output growth in Singapore regardless of the specification of capital shares. Human-capital-adjusted labor contributes 38% more than labor on average, and contributes the most to output growth in Singapore when capital share equals 0.35. Adjusted productivity contributes 43% less than productivity on average. These results are consistent with empirical evidence. For example, Mankiw et al. (1992) emphasize the importance of human capital accumulation as a good predictor of cross-country income differences. Jorgenson and Stiroh (2000) claim that a failure to incorporate labor quality leads to an overstatement of historical productivity growth. The absolute contribution of physical capital exhibits a countercyclical pattern before the 2000s, which is consistent with the claim that real business fixed investment booms in the early phase of recovery (Kahn, 1985). The synchronous absolute contributions of labor, human-capital-adjusted labor, and productivity during the same period can be explained by "labor hoarding"[9] (e.g., Burnside et al., 1993).

[9] Labor hoarding refers to a condition in which firms tend to hold on to labor during a downturn despite a declining demand for it. The main motivation is that it can be less costly to hold on to existing workers than to lay them off and rehire and train new workers (especially high-skill workers and workers acquired firm-specific skills) at higher costs when the economy recovers.

Table 2.1 The Absolute Contributions of Inputs and Productivity to Output Growth in Singapore Using Constant Capital Shares, 1980-2009

Period	Y(%)	K(%)	L(%)	L_H(%)	Capital Share	K(AC)	L(AC)	T(AC)	L_H(AC)	T_H(AC)
1980-86	0.343	0.602	0.040	0.127	0.49	0.295	0.021	0.028	0.065	-0.016
1986-92	0.533	0.375	0.264	0.347	0.49	0.184	0.134	0.215	0.177	0.173
1992-98	0.411	0.515	0.213	0.301	0.49	0.252	0.109	0.049	0.153	0.005
1998-04	0.311	0.312	0.067	0.114	0.49	0.153	0.034	0.124	0.058	0.099
2004-09	0.256	0.266	0.314	0.356	0.49	0.131	0.160	-0.035	0.181	-0.056
1980-09	1.854	2.070	0.898	1.245	0.49	1.014	0.458	0.382	0.635	0.205
1980-86	0.343	0.602	0.040	0.127	0.42	0.253	0.023	0.067	0.074	0.017
1986-92	0.533	0.375	0.264	0.347	0.42	0.157	0.153	0.223	0.201	0.175
1992-98	0.411	0.515	0.213	0.301	0.42	0.216	0.124	0.070	0.174	0.020
1998-04	0.311	0.312	0.067	0.114	0.42	0.131	0.039	0.141	0.066	0.113
2004-09	0.256	0.266	0.314	0.356	0.42	0.112	0.182	-0.038	0.206	-0.062
1980-09	1.854	2.070	0.898	1.245	0.42	0.870	0.521	0.464	0.722	0.263
1980-86	0.343	0.602	0.040	0.127	0.35	0.211	0.026	0.106	0.082	0.050
1986-92	0.533	0.375	0.264	0.347	0.35	0.131	0.171	0.231	0.226	0.177
1992-98	0.411	0.515	0.213	0.301	0.35	0.180	0.139	0.092	0.195	0.035
1998-04	0.311	0.312	0.067	0.114	0.35	0.109	0.043	0.158	0.074	0.127
2004-09	0.256	0.266	0.314	0.356	0.35	0.093	0.204	-0.041	0.231	-0.068
1980-09	1.854	2.070	0.898	1.245	0.35	0.725	0.584	0.546	0.809	0.321

Note: The percent sign (%) indicates the growth rate of each input. The acronym AC stands for the absolute contributions of inputs and productivity to output growth in Singapore.

Table 2.2 presents the percentage contributions of physical capital, labor, human-capital-adjusted labor, and productivity to output growth in Singapore using three constant capital shares of 0.49, 0.42, and 0.35 for the period 1980-2009, respectively. Overall, physical capital accounts for 39%-54% of output growth in Singapore. The percentage contribution of human-capital-adjusted labor that varies from 34% to 43% exceeds that of labor in all specifications of capital shares. The percentage contribution of adjusted productivity that varies from 11% to 17% is about 43% smaller than that of productivity on average. The percentage contribution of physical capital displays cyclical movements for the subperiod 1980-1998, and remains relatively stable for the subperiod 1998-2009. The percentage contributions of labor and human-capital-adjusted labor both increase for the subperiod 1980-1998, and fluctuate intensively since then. The procyclical percentage contribution of adjusted productivity is strongly positive for some subperiods (e.g., 1986-1992) and massively negative for other subperiods (e.g., 2004-2009), which is “at least partly attributable to business cycle fluctuations” (Young, 1992).

Table 2.2 The Percentage Contributions of Inputs and Productivity to Output Growth in Singapore Using Constant Capital Shares, 1980-2009

Period	Y(%)	K(%)	L(%)	L_H(%)	Capital Share	K(PC)	L(PC)	T(PC)	L_H(PC)	T_H(PC)
1980-86	0.343	0.602	0.040	0.127	0.49	0.859	0.060	0.081	0.189	-0.047
1986-92	0.533	0.375	0.264	0.347	0.49	0.344	0.252	0.404	0.332	0.324
1992-98	0.411	0.515	0.213	0.301	0.49	0.615	0.265	0.120	0.373	0.012
1998-04	0.311	0.312	0.067	0.114	0.49	0.492	0.109	0.398	0.188	0.320
2004-09	0.256	0.266	0.314	0.356	0.49	0.510	0.625	-0.135	0.708	-0.218
1980-09	1.854	2.070	0.898	1.245	0.49	0.547	0.247	0.206	0.342	0.111
1980-86	0.343	0.602	0.040	0.127	0.42	0.736	0.068	0.195	0.214	0.049
1986-92	0.533	0.375	0.264	0.347	0.42	0.295	0.287	0.418	0.377	0.328
1992-98	0.411	0.515	0.213	0.301	0.42	0.527	0.301	0.172	0.425	0.048
1998-04	0.311	0.312	0.067	0.114	0.42	0.422	0.125	0.454	0.213	0.365
2004-09	0.256	0.266	0.314	0.356	0.42	0.437	0.711	-0.148	0.806	-0.243
1980-09	1.854	2.070	0.898	1.245	0.42	0.469	0.281	0.250	0.389	0.142
1980-86	0.343	0.602	0.040	0.127	0.35	0.613	0.077	0.310	0.240	0.146
1986-92	0.533	0.375	0.264	0.347	0.35	0.246	0.321	0.433	0.423	0.331
1992-98	0.411	0.515	0.213	0.301	0.35	0.439	0.338	0.223	0.476	0.085
1998-04	0.311	0.312	0.067	0.114	0.35	0.352	0.140	0.509	0.239	0.409
2004-09	0.256	0.266	0.314	0.356	0.35	0.364	0.797	-0.161	0.903	-0.267
1980-09	1.854	2.070	0.898	1.245	0.35	0.391	0.315	0.294	0.436	0.173

Note: The percent sign (%) indicates the growth rate of each input. The acronym PC stands for the percentage contributions of inputs and productivity to output growth in Singapore.

Table 2.3 presents the annual absolute contributions of physical capital, labor, human-capital-adjusted labor, and productivity to output growth in Singapore using three constant capital shares of 0.49, 0.42, and 0.35 for the period 1980-2009, respectively. The annual absolute contribution of physical capital varies from 0.025 to 0.035, or approximately 39% to 54% of output growth in Singapore. The annual absolute contribution of labor varies from 0.016 to 0.020, or approximately 25% to 31% of output growth in Singapore. The average annual absolute contribution of human-capital-adjusted labor is 0.007 greater than that of labor, or approximately 11% of output growth in Singapore. The annual absolute contribution of productivity varies from 0.013 to 0.019, or approximately 20% to 29% of output growth in Singapore. Singapore has a steady decline in physical capital growth and a rapid growth of human-capital-adjusted labor during the same period. As one of the essential features of business cycles, adjusted productivity growth is significantly procyclical. This is consistent with many empirical results (e.g., Basu, 1996; Basu and Fernald, 2002; Burnside and Eichenbaum, 1996).

Table 2.3 The Annual Absolute Contributions of Inputs and Productivity to Output Growth in Singapore Using Constant Capital Shares, 1980-2009

Period	Y(%)	K(%)	L(%)	L_H(%)	K(AC)	L(AC)	T(AC)	L_H(AC)	T_H(AC)
1980-81	0.102	0.107	0.033	0.047	0.053, 0.045*, 0.038**	0.017, 0.019*, 0.021**	0.032, 0.038*, 0.043**	0.024, 0.027*, 0.031**	0.025, 0.029*, 0.033**
1981-82	0.069	0.119	0.024	0.038	0.058, 0.050*, 0.042**	0.012, 0.014*, 0.015**	-0.001, 0.006*, 0.012**	0.020, 0.022*, 0.025**	-0.009, -0.003*, 0.003**
1982-83	0.082	0.118	0.023	0.038	0.058, 0.049*, 0.041**	0.012, 0.013*, 0.015**	0.012, 0.019*, 0.026**	0.019, 0.022*, 0.025**	0.005, 0.011*, 0.016**
1983-84	0.084	0.115	0.008	0.022	0.056, 0.048*, 0.040**	0.004, 0.004*, 0.005**	0.024, 0.032*, 0.039**	0.011, 0.013*, 0.014**	0.017, 0.023*, 0.030**
1984-85	-0.007	0.083	-0.031	-0.016	0.041, 0.035*, 0.029**	-0.016, -0.018*, -0.020**	-0.032, -0.024*, -0.016**	-0.008, -0.009*, -0.011**	-0.039, -0.032*, -0.025**
1985-86	0.013	0.060	-0.016	-0.002	0.029, 0.025*, 0.021**	-0.008, -0.009*, -0.010**	-0.008, -0.003*, 0.002**	-0.001, -0.001*, -0.001**	-0.015, -0.011*, -0.006**
1986-87	0.102	0.054	0.047	0.060	0.026, 0.023*, 0.019**	0.024, 0.027*, 0.030**	0.052, 0.053*, 0.053**	0.031, 0.035*, 0.039**	0.045, 0.045*, 0.044**
1987-88	0.105	0.052	0.044	0.058	0.026, 0.022*, 0.018**	0.023, 0.026*, 0.029**	0.057, 0.058*, 0.058**	0.030, 0.034*, 0.038**	0.050, 0.050*, 0.050**
1988-89	0.097	0.061	0.049	0.063	0.030, 0.026*, 0.021**	0.025, 0.029*, 0.032**	0.042, 0.043*, 0.043**	0.032, 0.037*, 0.041**	0.035, 0.035*, 0.035**
1989-90	0.096	0.064	0.098	0.112	0.032, 0.027*, 0.023**	0.050, 0.057*, 0.064**	0.014, 0.012*, 0.009**	0.057, 0.065*, 0.073**	0.007, 0.004*, 0.000**
1990-91	0.065	0.070	-0.013	0.002	0.034, 0.029*, 0.024**	-0.006, -0.007*, -0.008**	0.037, 0.043*, 0.049**	0.001, 0.001*, 0.001**	0.029, 0.034*, 0.039**
1991-92	0.068	0.074	0.037	0.052	0.036, 0.031*, 0.026**	0.019, 0.022*, 0.024**	0.013, 0.016*, 0.018**	0.027, 0.030*, 0.034**	0.006, 0.007*, 0.009**

1992-93	0.109	0.077	0.006	0.021	0.038, 0.032*, 0.027**	0.003, 0.004*, 0.004**	0.068, 0.073*, 0.078**	0.011, 0.012*, 0.014**	0.061, 0.065*, 0.069**
1993-94	0.104	0.079	0.036	0.051	0.039, 0.033*, 0.028**	0.018, 0.021*, 0.023**	0.047, 0.050*, 0.053**	0.026, 0.029*, 0.033**	0.039, 0.041*, 0.043**
1994-95	0.068	0.083	0.034	0.049	0.040, 0.035*, 0.029**	0.018, 0.020*, 0.022**	0.010, 0.013*, 0.017**	0.025, 0.029*, 0.032**	0.002, 0.005*, 0.007**
1995-96	0.073	0.100	0.055	0.069	0.049, 0.042*, 0.035**	0.028, 0.032*, 0.036**	-0.005, -0.001*, 0.002**	0.035, 0.040*, 0.045**	-0.012, -0.010*, -0.007**
1996-97	0.080	0.099	0.062	0.076	0.048, 0.042*, 0.035**	0.032, 0.036*, 0.040**	-0.001, 0.002*, 0.005**	0.039, 0.044*, 0.050**	-0.008, -0.006*, -0.005**
1997-98	-0.023	0.078	0.020	0.034	0.038, 0.033*, 0.027**	0.010, 0.012*, 0.013**	-0.071, -0.067*, -0.063**	0.017, 0.020*, 0.022**	-0.078, -0.075*, -0.072**
1998-99	0.059	0.065	0.005	0.019	0.032, 0.027*, 0.023**	0.003, 0.003*, 0.003**	0.025, 0.029*, 0.033**	0.010, 0.011*, 0.012**	0.018, 0.021*, 0.024**
1999-00	0.085	0.069	0.038	0.050	0.034, 0.029*, 0.024**	0.020, 0.022*, 0.025**	0.032, 0.034*, 0.036**	0.026, 0.029*, 0.033**	0.026, 0.027*, 0.028**
2000-01	-0.010	0.060	0.023	0.029	0.029, 0.025*, 0.021**	0.012, 0.014*, 0.015**	-0.051, -0.048*, -0.046**	0.015, 0.017*, 0.019**	-0.054, -0.051*, -0.049**
2001-02	0.041	0.042	-0.005	0.001	0.021, 0.018*, 0.015**	-0.002, -0.003*, -0.003**	0.023, 0.026*, 0.030**	0.000, 0.000*, 0.000**	0.020, 0.023*, 0.026**
2002-03	0.043	0.035	-0.009	-0.004	0.017, 0.015*, 0.012**	-0.005, -0.005*, -0.006**	0.031, 0.034*, 0.037**	-0.002, -0.002*, -0.003**	0.028, 0.031*, 0.034**
2003-04	0.091	0.041	0.014	0.019	0.020, 0.017*, 0.014**	0.007, 0.008*, 0.009**	0.064, 0.066*, 0.068**	0.010, 0.011*, 0.013**	0.061, 0.063*, 0.064**
2004-05	0.072	0.038	0.041	0.046	0.019, 0.016*, 0.013**	0.021, 0.024*, 0.026**	0.033, 0.033*, 0.032**	0.023, 0.027*, 0.030**	0.030, 0.030*, 0.029**
2005-06	0.085	0.047	0.064	0.073	0.023, 0.020*, 0.016**	0.033, 0.037*, 0.042**	0.029, 0.028*, 0.027**	0.037, 0.043*, 0.048**	0.024, 0.023*, 0.021**

2006-07	0.087	0.058	0.080	0.089	0.028, 0.024*, 0.020**	0.041, 0.046, 0.052**	0.018, 0.017*, 0.015**	0.045, 0.052, 0.058**	0.013, 0.011*, 0.009**
2007-08	0.018	0.067	0.084	0.094	0.033, 0.028*, 0.023**	0.043, 0.049*, 0.055**	-0.058, -0.059*, -0.061**	0.048, 0.054*, 0.061**	-0.063, -0.065*, -0.066**
2008-09	-0.006	0.057	0.045	0.054	0.028, 0.024*, 0.020**	0.023, 0.026*, 0.029**	-0.057, -0.056*, -0.055**	0.027, 0.031*, 0.035**	-0.061, -0.061*, -0.061**
Average	0.064	0.071	0.031	0.043	0.035, 0.030*, 0.025**	0.016, 0.018*, 0.020**	0.013, 0.016*, 0.019**	0.022, 0.025*, 0.028**	0.007, 0.009*, 0.011**

Note: The values without an asterisk (*), with an *, and with two ** denote the contributions using constant capital shares of 0.49, 0.42, and 0.35, respectively. The percent sign (%) indicates the growth rate of each input. The acronym AC stands for the absolute contributions of inputs and productivity to output growth in Singapore.

Tables 2.4-2.6 re-examine the above contributions using time-varying capital shares that steadily decline from 0.49 for the subperiod 1980-1986 to 0.35 for the subperiod 2004-2009. Table 2.4 presents the absolute contributions of physical capital, labor, human-capital-adjusted labor, and productivity to output growth in Singapore using time-varying capital shares for the period 1980-2009. Again, physical capital contributes the most to output growth in Singapore, which is consistent with empirical findings from previous studies (e.g., Young, 1992). The contribution of physical capital in absolute terms has decreased since the 1990s though, which can be explained by a deceleration in the accumulation of physical capital and improvements in the quality of capital goods (Bercuson, 1995). The absolute contribution of human-capital-adjusted labor is greater and more volatile than that of labor across all subperiods. This result implies that estimation of contributions of various inputs without considering quality-adjusted labor input is biased, since it implicitly incorporates skill heterogeneity into productivity. The absolute contribution of productivity is overstated by approximately 0.039 on average. The volatile contribution of productivity in absolute terms partly reflects lack of measurement of intangible investment, such as research and development (R&D) and improved business processes (Fernald and Matoba, 2009; Oliner et al., 2008). On the whole, a decline in capital deepening is partly offset by improvements in labor quality and procyclical productivity growth.

Table 2.4 The Absolute Contributions of Inputs and Productivity to Output Growth in Singapore Using Time-Varying Capital Shares, 1980-2009

Period	Y(%)	K(%)	L(%)	L_H(%)	Capital Share	K(AC)	L(AC)	T(AC)	L_H(AC)	T_H(AC)
1980-86	0.343	0.602	0.040	0.127	0.49	0.295	0.021	0.028	0.065	-0.016
1986-92	0.533	0.375	0.264	0.347	0.455	0.170	0.144	0.219	0.189	0.174
1992-98	0.411	0.515	0.213	0.301	0.42	0.216	0.124	0.070	0.174	0.020
1998-04	0.311	0.312	0.067	0.114	0.385	0.120	0.041	0.150	0.070	0.120
2004-09	0.256	0.266	0.314	0.356	0.35	0.093	0.204	-0.041	0.231	-0.068
Average	0.371	0.414	0.180	0.249	0.42	0.179	0.107	0.085	0.146	0.046

Note: The percent sign (%) indicates the growth rate of each input. The acronym AC stands for the absolute contributions of inputs and productivity to output growth in Singapore.

Table 2.5 presents the percentage contributions of physical capital, labor, human-capital-adjusted labor, and productivity to output growth in Singapore using time-varying capital shares for the period 1980-2009. Physical capital accounts for almost half of output growth in Singapore on average. The percentage contribution of human-capital-adjusted labor that accounts for the most to output growth in Singapore for the subperiod 2004-2009 is approximately 34% greater than that of labor. Improvements in quality-adjusted human capital are important for Singapore given the nation’s relatively short length of schooling of adults (15 years and older) relative to the Group of Seven (G7) countries (Barro and Lee, 2001). The net effects of changes in the above contributions include lower positive contributions of productivity for some subperiods (e.g., 1998-2004), and higher negative contributions of productivity for other subperiods (e.g., 2004-2009). On average, the percentage contribution of productivity is overstated by approximately 0.108.

Table 2.5 The Percentage Contributions of Inputs and Productivity to Output Growth in Singapore Using Time-Varying Capital Shares, 1980-2009

Period	Y(%)	K(%)	L(%)	L_H(%)	Capital Share	K(PC)	L(PC)	T(PC)	L_H(PC)	T_H(PC)
1980-86	0.343	0.602	0.040	0.127	0.49	0.859	0.060	0.081	0.189	-0.047
1986-92	0.533	0.375	0.264	0.347	0.455	0.320	0.269	0.411	0.355	0.326
1992-98	0.411	0.515	0.213	0.301	0.42	0.527	0.301	0.172	0.425	0.048
1998-04	0.311	0.312	0.067	0.114	0.385	0.387	0.132	0.481	0.226	0.387
2004-09	0.256	0.266	0.314	0.356	0.35	0.364	0.797	-0.161	0.903	-0.267
Average	0.371	0.414	0.180	0.249	0.42	0.491	0.312	0.197	0.419	0.089

Note: The percent sign (%) indicates the growth rate of each input. The acronym PC stands for the percentage contributions of inputs and productivity to output growth in Singapore.

Table 2.6 presents the annual absolute contributions of physical capital, labor, human-capital-adjusted labor, and productivity to output growth in Singapore using time-varying capital shares for the period 1980-2009. The average annual absolute contribution of physical capital is 0.031, or approximately 48% of output growth in Singapore. Human-capital-adjusted labor plays an increasingly important role in contributing output growth in Singapore, especially for the subperiod 2004-2009. The average annual absolute contribution of human-capital-adjusted labor is 0.025 compared to that of labor that equals 0.018, or approximately 39% compared to 28% of output growth in Singapore. Again, the procyclical pattern of productivity growth matches business cycle fluctuations.

Table 2.6 The Annual Absolute Contributions of Inputs and Productivity to Output Growth in Singapore Using Time-Varying Capital Shares, 1980-2009

Period	Y(%)	K(%)	L(%)	L_H(%)	CapitalShare	K(AC)	L(AC)	T(AC)	L_H(AC)	T_H(AC)
1980-81	0.102	0.107	0.033	0.047	0.49	0.053	0.017	0.032	0.024	0.025
1981-82	0.069	0.119	0.024	0.038	0.49	0.058	0.012	-0.001	0.020	-0.009
1982-83	0.082	0.118	0.023	0.038	0.49	0.058	0.012	0.012	0.019	0.005
1983-84	0.084	0.115	0.008	0.022	0.49	0.056	0.004	0.024	0.011	0.017
1984-85	-0.007	0.083	-0.031	-0.016	0.49	0.041	-0.016	-0.032	-0.008	-0.039
1985-86	0.013	0.060	-0.016	-0.002	0.49	0.029	-0.008	-0.008	-0.001	-0.015
1986-87	0.102	0.054	0.047	0.060	0.455	0.025	0.025	0.052	0.033	0.045
1987-88	0.105	0.052	0.044	0.058	0.455	0.024	0.024	0.057	0.032	0.050
1988-89	0.097	0.061	0.049	0.063	0.455	0.028	0.027	0.042	0.034	0.035
1989-90	0.096	0.064	0.098	0.112	0.455	0.029	0.054	0.013	0.061	0.005
1990-91	0.065	0.070	-0.013	0.002	0.455	0.032	-0.007	0.040	0.001	0.032
1991-92	0.068	0.074	0.037	0.052	0.455	0.034	0.020	0.015	0.028	0.006
1992-93	0.109	0.077	0.006	0.021	0.42	0.032	0.004	0.073	0.012	0.065
1993-94	0.104	0.079	0.036	0.051	0.42	0.033	0.021	0.050	0.029	0.041
1994-95	0.068	0.083	0.034	0.049	0.42	0.035	0.020	0.013	0.029	0.005
1995-96	0.073	0.100	0.055	0.069	0.42	0.042	0.032	-0.001	0.040	-0.010
1996-97	0.080	0.099	0.062	0.076	0.42	0.042	0.036	0.002	0.044	-0.006
1997-98	-0.023	0.078	0.020	0.034	0.42	0.033	0.012	-0.067	0.020	-0.075
1998-99	0.059	0.065	0.005	0.019	0.385	0.025	0.003	0.031	0.012	0.023
1999-00	0.085	0.069	0.038	0.050	0.385	0.027	0.024	0.035	0.031	0.028
2000-01	-0.010	0.060	0.023	0.029	0.385	0.023	0.014	-0.047	0.018	-0.050
2001-02	0.041	0.042	-0.005	0.001	0.385	0.016	-0.003	0.028	0.000	0.025
2002-03	0.043	0.035	-0.009	-0.004	0.385	0.013	-0.006	0.036	-0.002	0.032
2003-04	0.091	0.041	0.014	0.019	0.385	0.016	0.008	0.067	0.012	0.063
2004-05	0.072	0.038	0.041	0.046	0.35	0.013	0.026	0.032	0.030	0.029
2005-06	0.085	0.047	0.064	0.073	0.35	0.016	0.042	0.027	0.048	0.021
2006-07	0.087	0.058	0.080	0.089	0.35	0.020	0.052	0.015	0.058	0.009
2007-08	0.018	0.067	0.084	0.094	0.35	0.023	0.055	-0.061	0.061	-0.066
2008-09	-0.006	0.057	0.045	0.054	0.35	0.020	0.029	-0.055	0.035	-0.061
Average	0.064	0.071	0.031	0.043	0.422	0.031	0.018	0.015	0.025	0.008

Note: The percent sign (%) indicates the growth rate of each input. The acronym AC stands for the absolute contributions of inputs and productivity to output growth in Singapore.

2.6 Conclusion

This essay re-estimates the contributions of various inputs influenced by quality-adjusted human capital and time-varying factor shares to Singapore's output growth for the period 1980-2009. Specifically, I extend the translog production function approach developed by Jorgenson et al. (1987) by incorporating human-capital-adjusted labor and the assumption of time-varying shares of physical capital. The results show that a decline in capital deepening is partly offset by improvements in labor quality and procyclical productivity growth. They also imply that estimation of contributions of various inputs without considering quality-adjusted labor input is biased.

This essay also provides some guidance to policymakers. To improve labor's contribution to output growth, the government ought to increase both quantity and quality of human capital. Becker et al. (1990) find that rates of return on investments in human capital increase until the stock of human capital is accumulated to a certain level. Considering sectors producing human capital use educated workers more intensively than sectors producing capital goods, policymakers should invest in the former (e.g., education industry) more than the latter to satisfy growing demand for skilled labor. Heckman (2011) argues that the U.S. underinvests in the very young and overinvests in mature adults with low skills due to a failure to recognize non-cognitive skills for evaluating educational interventions. The government thus should be careful to allocate investments in human capital among different groups of people (e.g., Hanushek and Woessmann, 2008).

Future research should be directed at the decomposition of inputs and output into components at firm and sectoral levels. For example, Fernald (2014) models capital growth as a weighted average of the growth of 15 disaggregated types of components using estimated factor payments. The educational-attainment-based index of human capital per person can be combined with other labor market variables besides employment, such as hours of work and labor compensation. Furthermore, the impact of quality-adjusted human capital on labor's contribution to output growth can be attributed to factors in addition to education, such as work experience.

CHAPTER 3

THE DETERMINANTS OF INNOVATION: EVIDENCE FROM THE GROUP OF TWENTY (G20), 1996-2011

3.1 Introduction

Innovation plays an increasingly critical role in improving the standard of living measured by real GDP per capita. The World Bank considers openness, intellectual property rights protection, and FDI as principal channels for acquiring imported knowledge (the World Bank, 1998). Other factors, such as imports (especially high-technology imports), patent regime, and R&D have also been studied for countries at different levels of development (e.g., Maskus and Penubarti, 1995). Economists find that the determinants and diffusion of innovation between developed countries are different from those between developed and developing countries (e.g., Blankley et al., 2006; Schneider, 2005). Founded in 1999, the G20 is a forum of 19 countries[10] and the EU that accounts for 90% of the world's output and 80% of the world's trade. It was founded to coordinate policies at the international level, and to make globalization a smoother, more harmonious and sustainable process.

[10] Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, the Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, and the United States of America.

This essay makes three contributions to the literature. First, it complements previous studies by using different country groups of the G20 due to limitations in data availability and different research purposes. The G20 consists not only of the world's most influential developed countries, such as the U.S., Japan, and Germany, but also of major developing countries, such as China, India, and Mexico, measured by output levels and trading volumes. Second, I find that the determinants of innovation differ over time and across G20 countries. Third, I examine and compare the innovation trends in Singapore with the empirical results in different country groups of the G20 to explore the determinants of innovation in Singapore. I find that a decline in capital deepening is partly offset by improvements in labor quality and procyclical productivity growth in Chapter 2. Since productivity is a key economic indicator of innovation (Jorgenson, 2011), it makes sense to explore the determinants of innovation for a deeper understanding of productivity growth in Singapore.

In this essay, I measure the contemporaneous and one-period-lagged (i.e., lagged by one year) effects of the level of economic development, R&D spending, FDI net inflows, and infrastructure on innovation using a unique panel data set of 17 G20 countries and the EU as a whole for the period 1996-2011. I construct the panel data set sourced from the WDI 2014. R&D spending and infrastructure have significant positive contemporaneous and one-period-lagged effects on innovation in the pooled sample of G20 countries. If the pooled sample is split into developed and developing countries, the positive effect of R&D spending on innovation is stronger in developing countries than in developed countries. The one-period-lagged effect of R&D spending on innovation is weaker than the contemporaneous effect in developed countries. Infrastructure and FDI net inflows are effective in promoting innovation in developing countries, while their contemporaneous effects on innovation are not significant in developed countries. On the whole, this essay highlights the economic importance of R&D spending and infrastructure relative to that of FDI net inflows and the level of economic development addressed in traditional studies. It also implies that routinely pooling developed and developing countries can result in misleading conclusions and inappropriate policy recommendations. Besides relying on infrastructure to promote innovation, Singapore ought to apply R&D and technology spillovers to domestic enterprises more efficiently.

The remainder of this essay is organized as follows. Section 3.2 gives a brief overview of the determinants of innovation. Section 3.3 describes the data. Section 3.4 discusses the methodology. Section 3.5 presents the results. Section 3.6 provides policy implications for Singapore. Section 3.7 concludes.

3.2 Literature Review

The stock of human capital and the amount of R&D spending are positively correlated with innovation (Griliches, 1984). The quality of human capital affects innovation as well. For example, Ratanawaraha (2002) claims that improvements in innovation require a certain level of human capital achieved. Roy (1997) discusses how the quality of human capital affects a country’s innovation and long-term economic growth.

Factors that affect the profitability of innovation, such as the size of domestic market and the level of economic development, can determine innovation. For example, Schneider (2005) considers real GDP per capita as a proxy for the size of domestic market as one of the determinants of innovation in developed and developing countries. Stern et al. (2002) claim that the production function for international patents also depends on real GDP per capita as a proxy for the stock of knowledge.

Several studies indicate that the composition of imports in a country affects innovation. For example, Coe and Helpman (1995) find that foreign R&D activities have a stronger impact on domestic productivity growth the more open a country is to trade in 22 developed countries. Coe et al. (1997) extend the analysis to 77 developing countries. They find that total factor productivity in developing countries increases with a higher level of imports of intermediate products and capital equipment from developed countries with a high level of R&D capital stock. Eaton and Kortum (1996) indicate that imports, geographical distance, and human capital play a much larger role than other factors in accounting for technology diffusion between industrialized countries.

Grossman and Helpman (1995) claim that FDI directly and indirectly disseminates technology. Cheung and Lin (2004) conclude that FDI promotes innovation through knowledge spillovers, such as reverse engineering and skilled labor turnovers. Using provincial data between 1995 and 2000, they find positive effects of FDI on the number of domestic patent applications in China. Other studies, however, state that FDI does not significantly contribute to innovation[11].

A country's ability to absorb, adapt, and apply foreign technologies may depend on its infrastructure. For example, Bardhan (1995) claims that technology transfer via FDI is constrained not so much by restrictive government policies in a host country as by the lack of adequate infrastructure.

3.3 Data

This essay conducts an empirical analysis using a unique panel data set of 17 G20 countries[12] and the EU as a whole, which consists of 28 high- and middle-income countries[13], for the period 1996-2011. Note that France, Germany, Italy, and the United Kingdom are member countries of both the G20 and the EU. Developed countries are referred to as high-income economies with a GNI per capita of $12,736 or more. Developing countries are referred to as upper- and lower-middle-income economies[14] with a GNI per capita of more than $1,045 but less than $12,736 (the World Bank Updated

[11] Such statements include: 1) FDI inflows do not significantly affect either domestic innovation or imitation (Connolly, 1998); 2) Inward FDI flows are not major channels of technology transfer (Lichtenberg and van Pottelsberghe de la Potterie, 1996); 3) There exists no relationship between foreign presence and productivity growth in domestic firms (Haddad and Harrison, 1993).

[12] Italy is excluded due to missing values for innovation. Indonesia and Saudi Arabia are excluded due to missing values for R&D spending.

[13] The World Bank classifies all economies in the world into four groups: high, upper-middle, lower-middle, and low, based on gross national income (GNI) per capita in the U.S. dollars for the previous year. In the EU, only Bulgaria and Romania are middle-income countries, and all other countries are high-income countries.

[14] Upper- and lower-middle-income economies are separated with a GNI per capita of $4,125.

Income Classifications 2014). I replace the missing value in a given year with either an average of the two neighboring values if available or the last observed value if either of the two neighboring values is not available[15]. Table 3.1 provides information regarding missing data on the dependent and independent variables. The annual observations are taken from the WDI 2014. All variables are natural-log transformed and in constant 2005 U.S. dollars.

Table 3.1 Missing Data on the Dependent and Independent Variables

Country	Variable with Missing Data	Year with Missing Data	Number of Missing Data
Argentina	Innovation	2009-2011	3
Australia	R&D Spending	1997, 1999, 2001, 2003, 2005, 2007, and 2009	7
Brazil	R&D Spending	1996-1999	4
Indonesia	R&D Spending	1996-2011	16
Italy	Innovation	1996-2011	16
Saudi Arabia	Innovation	2008-2009	2
Saudi Arabia	R&D Spending	1996-2011	16
South Africa	R&D Spending	1996, 1998-2000, and 2002	5

The proxy for innovation (denoted by "Innov") is the number of patent applications by residents of a country each year. According to the WDI 2014, patent applications refer to "those filed through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights for an invention–a product or process that provides a new way

[15] According to Williams (2015), a common strategy, particularly if the missing data are not too numerous, is to impute the missing values with the overall mean.

of doing something, or offers a new technical solution to a problem". It is preferable to use patent applications instead of granted patents, given the time gap between the application process and the issuance of a patent (Schneider, 2005). While the number of patent applications by residents of a country each year may not fully reflect a country's general levels of innovation, it is still "the most concrete and comparable measure of innovative output across countries and time" (Stern et al., 2002).

Real GDP per capita (denoted by "GDPpc") is a country's GDP converted to constant 2005 U.S. dollars divided by the midyear population. Besides measuring the level of economic development, real GDP per capita has been used as a proxy for the stock of knowledge in a production function for international patents (Stern et al., 2002).

According to the WDI 2014, R&D spending (denoted by "R&D") consists of "current and capital expenditures (both public and private) on creative work undertaken systematically to increase knowledge of humanity, culture, and society, and the use of knowledge for new applications". Previous studies have shown that R&D spending is relevant in explaining innovation in developed and developing countries. For example, Griliches (1984) finds that R&D spending is positively correlated with innovation in developed countries.

According to the WDI 2014, FDI net inflows (denoted by "FDI") refer to "the net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise other than that of the investor. It is the sum of equity capital, reinvested earnings, other long-term capital, and short-term capital, as shown in the balance of payments". Since FDI net inflows can be negative in instances of reverse investment or disinvestment, the natural log is taken only if it is positive, and 0 otherwise (Battese, 1997).

Following Schneider (2005), I use electricity production (denoted by "Elecp") as a proxy for infrastructure. According to the WDI 2014, electricity production covers "generation by geothermal, solar, wind, tide and wave energy, and combustible renewables and waste, in addition to traditional generation by hydropower, coal, oil, gas, and nuclear power. Production includes the output of electricity plants as well as that of combined heat and power plants".

3.4 Methodology

The empirical specification of regression models in this essay is based on the theoretical models developed by Grossman and Helpman (1991). The baseline model is a pooled OLS regression model that takes the following form:

$$Innov_{it} = \beta_0 + X'_{it}\beta_1 + \varepsilon_{it}, \qquad i = 1, 2, ..., 14; t = 1, 2, ..., 16 \tag{3.4.1}$$

where the dependent variable $Innov_{it}$ is the number of patent applications by residents of country i at time period t, X'_{it} is a K-dimensional row vector of independent variables in country i at time period t, consisting of 1) GDP per capita in constant 2005 U.S. dollars, GDPpc, 2) R&D spending, R&D, 3) FDI net inflows, FDI, and 4) electricity production[16], Elecp, ε_{it} is the random error term in country i at time period t, β_0 is a constant term, and β_1 is a K-dimensional column vector of coefficients for the vector of independent variables, X'_{it}. Under the assumptions of a linear relationship between the dependent and independent variables, a strictly exogenous relationship between the independent variables and random error terms, and the homoscedasticity and independence of random error terms in small samples, the pooled OLS estimator is unbiased and consistent. However, the pooled OLS estimator becomes biased in the presence of unobserved country-specific heterogeneity. The usual standard error of the pooled OLS estimator is thus biased, and tests (e.g., t- and F-tests) based on it are not valid (Schmidheiny, 2015).

To determine whether the pooled OLS estimator or the fixed effects estimator is more appropriate, I test the joint significance of the fixed effects estimator in least squares specifications by using the sum of residual squares (e.g., F-test). If the corresponding p-value is less than the chosen significance level of 0.05, I reject the null hypothesis indicating that the cross-section effects are redundant, and the fixed effects estimator is more appropriate. Similarly, I evaluate the significance of the period dummies in an unrestricted specification that has period effects only against a restricted specification that has cross-section effects only.

[16] As indicated in Section 3.3, I use electricity production as a proxy for infrastructure.

To capture possible unobserved country-specific heterogeneity, I add fixed and random effects to the baseline model, respectively. The extended model takes the following form:

$$Innov_{it} = \beta_0 + X'_{it}\beta_1 + \alpha_i + \mu_{it} \quad (3.4.2)$$

where α_i is the time-invariant, unobserved country-specific effect in country i and μ_{it} is the idiosyncratic error term that is assumed to be uncorrelated with the vector of independent variables, X'_{it}, and α_i. The individual-specific effect is a random variable that can be correlated with the independent variables in the fixed effects model, and uncorrelated with the independent variables in the random effects model (Wooldridge, 2002). The key distinction between the fixed and random effects models is that the latter assumes that the time-invariant, unobserved country-specific effect is uncorrelated with the explanatory variables, while the former allows them to be correlated (Wooldridge, 2002). Following Schmidheiny (2015), the fixed effects estimator is unbiased and consistent under the assumption of identifiability of the vector of coefficients, β_1, besides the three assumptions for the pooled OLS estimator given above. The usual standard error of the fixed effects estimator is significantly underestimated in the presence of serial correlation of the idiosyncratic error term (Bertrand et al., 2004). The random effects estimator is a feasible generalized least squares (GLS) estimator. It is consistent and asymptotically normally distributed under the assumption of the independent relationship between the individual-specific effect and the independent variables and that of constant variance of the individual-specific effect, besides the assumptions for the fixed effects estimator

(Schmidheiny, 2015). Sometimes we suspect that there may exist the time-specific effect, δ_t, that affects all countries in the same way such that

$$Innov_{it} = \beta_0 + X'_{it}\beta_1 + \alpha_i + \delta_t + \mu_{it} \tag{3.4.3}$$

The random effects estimator is preferred to the fixed effects estimator if the individual-specific effect is uncorrelated with error terms. The Hausman test, with a null hypothesis indicating that the coefficients estimated by the fixed and random effects estimators are the same against the alternative hypothesis of different coefficients, is used to determine whether the fixed effects estimator or the random effects estimator is more appropriate (Wooldridge, 2002). Based on the results of the likelihood function (e.g., Chi-square test), if the corresponding p-value is less than the chosen significance level of 0.05, I reject the null hypothesis and choose the fixed effects estimator. If I do not reject the null hypothesis, the random effects estimator is preferred then.

To shed light on the impact of the level of economic development, R&D spending, FDI net inflows, and infrastructure on subsequent innovation, I re-estimate the baseline model by using the independent variables lagged by one year as follows:

$$Innov_{it} = \beta_0 + X'_{it-1}\beta_1 + \varepsilon_{it}, \quad i = 1, 2, ..., 14; t = 1, 2, ..., 16 \tag{3.4.4}$$

where X'_{it-1} is a K-dimensional row vector of independent variables in country i at time period t-1.

I also include possible time-invariant, individual-specific effect, α_i, and the lagged time-specific effect, δ_{t-1}, in Equation (3.4.4) such that

$$Innov_{it} = \beta_0 + X'_{it-1}\beta_1 + \alpha_i + \mu_{it} \quad (3.4.5)$$

$$Innov_{it} = \beta_0 + X'_{it-1}\beta_1 + \alpha_i + \delta_{t-1} + \mu_{it} \quad (3.4.6)$$

3.5 Results

Table 3.2 presents the results of regression analysis of innovation in a subset of 13 G20 countries, consisting of 7 developed countries (Argentina, Australia, Canada, Japan, Korea, Russia, the United States) and 6 developing countries (Brazil, China, India, Mexico, Turkey, South Africa), and the EU as a whole, consisting of 26 developed countries including France, Germany, Italy, and the United Kingdom as individual G20 countries and 2 developing countries (Bulgaria and Romania). Based on the results of the likelihood ratio test and the Hausman test shown in rows 9 and 10, I use the fixed effects model in regression models (4) and (6) and the random effects model in the remaining four regression models. The negative coefficients of the level of economic development are not statistically significant at the significance level of 0.05 in all regression models except regression model (6). This result can be explained as follows. Countries in the early stages of economic development usually have lower costs of absorbing foreign technology than of innovating on their own. The marginal cost of absorbing foreign technology increases as these countries grow, until eventually exceeds that of innovating on their own. The negative relationship between the level of economic development and innovation may depend on the structural characteristics of a country's national innovation system[17] as well. For example, it takes longer for countries that rely on foreign technology lacking close domestic substitutes to accumulate knowledge and skills for domestic innovation. R&D spending, whose positive coefficients are statistically significant at the significance level of 0.01 in regression models (1) through (6), exerts a positive effect on innovation as expected (e.g., Griliches, 1984; Coe and Helpman, 1995; Schneider, 2005). The positive impact of FDI net inflows is not statistically significant. This result is consistent with the findings in previous studies: 1) FDI inflows do not significantly affect either domestic innovation or imitation (Connolly, 1998); 2) Inward FDI flows are not major channels of technology transfer (Lichtenberg and van Pottelsberghe de la Potterie, 1996); 3) There exists no relationship between foreign presence and productivity growth in domestic firms (Haddad and Harrison, 1993). Infrastructure has a positive, statistically significant impact on innovation as expected (e.g., Besley et al., 2013; Koh, 2006).

[17] The national innovation system refers to the flows of technology and information among individuals, firms, and institutions.

Table 3.2 Regression Analysis of Innovation in G20 Countries

Dep.: LnInnov	Random Effects (RE) (1)	RE (2)	RE (3)	Fixed Effects (FE) (4)	RE (5)	FE (6)
LnGDPpc	-0.373 (-1.80)*	-0.378 (-1.83)*	-0.381 (-1.88)*	-0.444 (-1.50)*	-0.311 (-1.52)*	-0.673 (-2.33)**
LnR&D	1.403 (12.96)***	1.632 (13.08)***	1.402 (13.16)***	1.764 (10.49)***	0.925 (5.51)***	1.327 (6.91)***
LnFDI	-	-	0.006 (0.99)	0.008 (1.28)	0.004 (0.74)	0.006 (0.96)
LnElecp	-	-	-	-	0.791 (3.69)***	0.982 (4.19)***
Cons.	-20.217 (-16.02)***	-25.512 (-13.28)***	-20.258 (-16.14)***	-28.152 (-12.54)***	-31.083 (-9.81)***	-42.379 (-10.53)***
Obs.	224	224	224	224	224	224
R^2	0.731	0.756	0.733	0.989	0.747	0.989
Cross-Section F-statistic (Prob.)	212.587 (0.000)	226.161 (0.000)	207.624 (0.000)	221.760 (0.000)	224.785 (0.000)	241.736 (0.000)
Cross-Section Chi-sq. statistic (Prob.)	0.591 (0.744)	5.752 (0.056)	2.522 (0.471)	7.892 (0.048)	5.992 (0.200)	11.440 (0.022)

Note: Time dummies are included in regression models (2), (4), and (6). The t-statistics are presented in the parentheses below the corresponding coefficients. *, **, and *** denotes the significance level of 0.10, 0.05, and 0.01, respectively.

Table 3.3 presents the results of regression analysis of innovation in a subset of 10 developed G20 countries consisting of Argentina, Australia, Canada, France, Germany, Japan, the Republic of Korea, Russia, the United Kingdom, and the United States of America. I do not include the EU as an aggregate because it covers developing countries (Bulgaria and Romania) that cannot be excluded. As indicated above, Italy and Saudi Arabia are excluded due to missing values for innovation and R&D spending. Table 3.4 presents the results of regression analysis of innovation in a subset of 6 developing G20 countries consisting of Brazil, China, India, Mexico, South Africa, and Turkey. I do not include Bulgaria and Romania due to missing values for innovation. Indonesia is excluded due to missing values for R&D spending. Based on the results of the likelihood ratio test and the Hausman test shown in rows 9 and 10, I use the fixed effects model in all regression models shown in Table 3.3 and regression model (6) shown in Table 3.4, and the random effects model in regression models (1) through (5) shown in Table 3.4. The positive, statistically significant coefficients of R&D spending shown in Tables 3.3 and 3.4 imply that R&D spending promotes innovation in developed and developing countries. Moreover, its impact on innovation in developing countries is greater than in developed countries. This result can be explained as follows. Although a large portion of R&D activities take place in the U.S., Western Europe, and Japan, R&D spending in developing countries (especially the BRICs countries[18]) has grown rapidly (The UNESCO Institute for Statistics, 2010). A gradual shift in the global distribution of R&D spending from developed to developing countries enriches innovation sources and reshapes trade patterns of a country. For example, business expenditure on R&D has been an important supplement for R&D spending by the government and the higher education sector in developing countries. China and India have benefited greatly from the explosive growth of R&D spending sponsored by foreign multinational corporations (MNCs), and spread technology spillovers to domestic firms. FDI net inflows and infrastructure make contributions to innovation in developing countries as well.

[18] The BRICs countries are Brazil, Russia, India, China, and South Africa.

Table 3.3 Regression Analysis of Innovation in Developed Countries of the G20

Dep.: LnInnov	FE (1)	FE (2)	FE (3)	FE (4)	FE (5)	FE (6)
LnGDPpc	0.223 (1.09)	0.099 (0.48)	0.217 (1.06)	0.079 (0.38)	0.189 (0.91)	0.076 (0.36)
LnR&D	0.439 (3.85)***	0.688 (5.47)***	0.442 (3.85)***	0.695 (5.50)***	0.373 (2.90)***	0.681 (4.85)***
LnFDI	-	-	0.001 (0.33)	0.002 (0.74)	0.001 (0.29)	0.002 (0.71)
LnElecp	-	-	-	-	0.178 (1.18)	0.035 (0.23)
Cons.	-2.832 (-2.30)**	-7.575 (-3.78)***	-2.865 (-2.32)**	-7.596 (-3.79)***	-5.743 (-2.11)**	-8.159 (-2.59)***
Obs.	160	160	160	160	160	160
R^2	0.995	0.996	0.995	0.996	0.995	0.996
Cross-Section F-statistic (Prob.)	425.192 (0.000)	467.630 (0.000)	408.613 (0.000)	450.019 (0.000)	202.149 (0.000)	213.938 (0.000)
Cross-Section Chi-sq. statistic (Prob.)	18.982 (0.000)	12.871 (0.002)	25.073 (0.000)	17.687 (0.001)	45.492 (0.000)	35.222 (0.000)

Note: Time dummies are included in regression models (2), (4), and (6). The t-statistics are presented in the parentheses below the corresponding coefficients. *, **, and *** denotes the significance level of 0.10, 0.05, and 0.01, respectively.

Table 3.4 Regression Analysis of Innovation in Developing Countries of the G20

Dep.: LnInnov	RE (1)	RE (2)	RE (3)	RE (4)	RE (5)	FE (6)
LnGDPpc	-0.339 (-1.76)*	-0.332 (-1.66)*	-0.354 (-1.64)	-0.355 (-1.61)	-0.076 (-0.50)	-1.967 (-3.44)***
LnR&D	1.661 (16.18)***	1.730 (11.93)***	1.556 (12.74)***	1.647 (10.48)***	0.875 (3.61)***	1.433 (4.44)***
LnFDI	-	-	0.113 (2.12)**	0.160 (2.67)***	0.093 (1.83)*	0.173 (3.05)***
LnElecp	-	-	-	-	0.934 (3.02)***	2.091 (3.71)***
Cons.	-26.530 (-16.83)***	-28.130 (-9.36)***	-26.714 (-16.94)***	-29.829 (-9.90)***	-38.226 (-9.32)***	-68.111 (-6.69)***
Obs.	96	96	96	96	96	96
R^2	0.842	0.862	0.847	0.872	0.872	0.982
Cross-Section F-statistic (Prob.)	33.531 (0.000)	32.222 (0.000)	35.703 (0.000)	36.944 (0.000)	16.083 (0.000)	19.365 (0.000)
Cross-Section Chi-sq. statistic (Prob.)	0.011 (0.994)	0.457 (0.796)	0.525 (0.913)	1.963 (0.580)	7.948 (0.094)	17.504 (0.002)

Note: Time dummies are included in regression models (2), (4), and (6). The t-statistics are presented in the parentheses below the corresponding coefficients. *, **, and *** denotes the significance level of 0.10, 0.05, and 0.01, respectively.

Table 3.5 presents the results of regression analysis of innovation with one-period-lagged independent variables in the subset of 41 G20 countries (33 developed and 8 developing) from Table 3.2. Based on the results of the likelihood ratio test and the Hausman test shown in rows 9 and 10, I use the random effects model in regression models (1) through (5) and the fixed effects model in regression model (6). The coefficients of independent variables, which are all statistically significant except those for FDI net inflows, show that the contemporaneous and one-period-lagged effects of the level of economic development on innovation are negative, while that of R&D spending, FDI net inflows, and infrastructure on innovation are positive. Moreover, the one-period-lagged effects of the level of economic development, R&D spending, and infrastructure on innovation are stronger than their contemporaneous counterparts. However, the one-period-lagged effects of FDI net inflows are not statistically significant.

Table 3.5 Regression Analysis of Innovation with One-Period-Lagged Independent Variables in G20 Countries

Dep.: LnInnov	RE (1)	RE (2)	RE (3)	RE (4)	RE (5)	FE (6)
$LnGDPpc_{-1}$	-0.473 (-2.21)**	-0.444 (-2.07)**	-0.475 (-2.25)**	-0.453 (-2.14)**	-0.397 (-1.86)*	-0.821 (-2.66)***
$LnR\&D_{-1}$	1.450 (12.95)***	1.637 (12.58)***	1.448 (13.07)***	1.634 (12.71)***	0.935 (5.43)***	1.342 (6.78)***
$LnFDI_{-1}$	-	-	0.004 (0.54)	0.008 (1.18)	0.002 (0.32)	0.006 (1.00)
$LnElecp_{-1}$	-	-	-	-	0.864 (3.93)***	1.128 (4.66)***
Cons.	-20.339 (-15.04)***	-24.946 (-12.13)***	-20.352 (-15.08)***	-24.973 (-12.23)***	-32.401 (-9.76)***	-45.271 (-10.44)***
Obs.	210	210	210	210	210	210
R^2	0.712	0.737	0.713	0.739	0.732	0.990
Cross-Section F-statistic (Prob.)	196.031 (0.000)	207.028 (0.000)	191.658 (0.000)	204.134 (0.000)	212.249 (0.000)	228.670 (0.000)
Cross-Section Chi-sq. statistic (Prob.)	0.734 (0.693)	5.543 (0.063)	2.374 (0.499)	7.475 (0.058)	7.643 (0.106)	13.087 (0.011)

Note: Time dummies are included in regression models (2), (4), and (6). The t-statistics are presented in the parentheses below the corresponding coefficients. *, **, and *** denotes the significance level of 0.10, 0.05, and 0.01, respectively.

Tables 3.6 and 3.7 presents the results of regression analysis of innovation with one-period-lagged independent variables in the subset of 10 developed G20 countries and

6 developing G20 countries from Tables 3.3. and 3.4, respectively. Based on the results of the likelihood ratio test and the Hausman test shown in rows 9 and 10, I use the fixed effects model in all regression models in Table 3.6 and regression model (6) in Table 3.7, and the random effects model in regression models (1) through (5) in Table 3.7. As shown in rows 3 of Tables 3.3 and 3.6, the contemporaneous and one-period-lagged effects of R&D spending on innovation in developed countries are both positive and statistically significant. Moreover, the one-period-lagged effect is weaker than the contemporaneous counterpart, which is consistent with the findings in previous studies. For example, Klette and Griliches (2000) claim that the growth of R&D spending is a prerequisite for sustainable growth of innovation. Doran et al. (2013) find that the efficiency of an extra unit of R&D spending declines as domestic and foreign firms increase R&D spending per worker in developed countries. The previous year's infrastructure has a positive, statistically significant impact on the current year's innovation in developed countries. For example, Sivak et al. (2011) claim that the quality of infrastructure, especially the quality of transport, IT, and financial infrastructure, is one of the determinants of innovation in developed countries. The one-period-lagged impact of FDI net inflows is stronger than the contemporaneous counterpart. This result can be explained by the spillover effects of FDI on innovation in developing countries in particular (e.g., Hale and Long, 2006; Gorodnichenko et al., 2007). As indicated above, Cheung and Lin (2004) find positive spillover effects of FDI on the number of patent applications by residents of China using provincial data between 1995 and 2000.

Table 3.6 Regression Analysis of Innovation with One-Period-Lagged Independent Variables in Developed Countries of the G20

Dep.: LnInnov	FE (1)	FE (2)	FE (3)	FE (4)	FE (5)	FE (6)
$LnGDPpc_{-1}$	0.323 (1.50)	0.224 (1.05)	0.335 (1.54)	0.211 (0.98)	0.248 (1.17)	0.170 (0.80)
$LnR\&D_{-1}$	0.334 (2.73)***	0.580 (4.33)***	0.328 (2.67)***	0.587 (4.34)***	0.163 (1.24)	0.452 (3.19)***
$LnFDI_{-1}$	-	-	-0.002 (-0.60)	0.001 (0.43)	-0.002 (-0.66)	0.001 (0.28)
$LnElecp_{-1}$	-	-	-	-	0.455 (3.03)***	0.386 (2.63)***
Cons.	-1.304 (-0.97)	-6.202 (-2.88)***	-1.239 (-0.92)	-6.274 (-2.90)***	-8.698 (-3.12)***	-13.042 (-3.91)***
Obs.	150	150	150	150	150	150
R^2	0.995	0.996	0.995	0.996	0.995	0.996
Cross-Section F-statistic (Prob.)	405.267 (0.000)	460.088 (0.000)	392.703 (0.000)	446.246 (0.000)	211.577 (0.000)	231.379 (0.000)
Cross-Section Chi-sq. statistic (Prob.)	21.659 (0.000)	14.958 (0.001)	27.180 (0.000)	19.066 (0.000)	47.166 (0.000)	35.427 (0.000)

Note: Time dummies are included in regression models (2), (4), and (6). The t-statistics are presented in the parentheses below the corresponding coefficients. *, **, and *** denotes the significance level of 0.10, 0.05, and 0.01, respectively.

Table 3.7 Regression Analysis of Innovation with One-Period-Lagged Independent Variables in Developing Countries of the G20

Dep.: LnInnov	RE (1)	RE (2)	RE (3)	RE (4)	RE (5)	FE (6)
$LnGDPpc_{-1}$	-0.405 (-1.97)*	-0.368 (-1.72)*	-0.439 (-1.89)*	-0.387 (-1.63)	-0.216 (-1.15)	-1.835 (-2.79)***
$LnR\&D_{-1}$	1.712 (15.74)***	1.717 (10.80)***	1.606 (12.45)***	1.623 (9.537)***	1.085 (3.98)***	1.532 (4.38)***
$LnFDI_{-1}$	-	-	0.121 (2.25)**	0.191 (3.09)***	0.109 (2.08)**	0.203 (3.36)***
$LnElecp_{-1}$	-	-	-	-	0.719 (2.01)**	1.719 (2.78)***
Cons.	-27.026 (-15.77)***	-27.449 (-8.14)***	-27.222 (-15.98)***	-29.637 (-8.87)***	-36.303 (-7.47)***	-62.034 (-5.42)***
Obs.	90	90	90	90	90	90
R^2	0.833	0.847	0.840	0.863	0.852	0.981
Cross-Section F-statistic (Prob.)	35.369 (0.000)	31.948 (0.000)	38.222 (0.000)	38.611 (0.000)	19.590 (0.000)	21.344 (0.000)
Cross-Section Chi-sq. statistic (Prob.)	0.327 (0.849)	0.143 (0.931)	0.804 (0.849)	1.476 (0.688)	6.678 (0.154)	10.279 (0.036)

Note: Time dummies are included in regression models (2), (4), and (6). The t-statistics are presented in the parentheses below the corresponding coefficients. *, **, and *** denotes the significance level of 0.10, 0.05, and 0.01, respectively.

3.6 Policy Implications for Singapore

Table 3.8 presents descriptive statistics of resident patent applications and resident patent applications per million population in G20 countries and Singapore. The average number of resident patent applications in developed countries is larger than its counterpart in developing countries in the G20. Residents of Japan, the United States, and Korea file the three largest numbers of patent applications in developed countries in the G20. Residents of China, India, and Brazil file the three largest numbers of patent applications in developing countries in the G20. The average number of resident patent applications in Singapore is 594.5, which is only larger than that in Indonesia and Saudi Arabia in the G20. Although the average number of resident patent applications per million population in Singapore is larger than that in all developing countries in the G20, it is smaller than its counterpart in over 2/3 developed countries in the G20. These results are in contrast with Singapore's level of economic development, considering that Singapore is the world's third richest country measured by GDP per capita based on purchasing power parity[19].

[19] World Economic Outlook Database, April 2014.

Table 3.8 Descriptive Statistics of Resident Patent Applications (RPAs) and RPAs per Million Population in G20 Countries and Singapore

	Number of RPAs				Number of RPAs per Million Population			
Country	Min	Max	Mean	SD	Min	Max	Mean	SD
Argentina	691	1097	871.56	126.38	18.44	30.97	22.72	3.82
Australia	1760	2837	2309.38	367.21	95.05	137.07	114.36	13.85
Canada	2583	5522	4387.56	795.02	87.05	169.54	137.00	21.01
France	12916	14748	13961.19	609.30	216.16	229.97	223.39	4.58
Germany	42322	51736	47766.56	2195.66	516.66	629.30	581.21	26.10
Japan	287580	384201	344599.40	30686.67	2249.93	3028.95	2706.82	247.08
Korea	50596	138034	97602.63	30935.58	1093.11	2772.91	2028.78	599.58
Russia	15106	28722	23553.38	4170.47	102.13	201.06	162.93	30.66
Saudi Arabia	27	347	118	92.73	1.40	12.05	4.64	3.05
United Kingdom	15343	22050	18544.94	2180.22	242.54	374.41	308.95	42.83
United States	106892	247750	189521.60	45022.65	396.79	801.20	645.19	128.01
Brazil	2491	4695	3647.56	691.65	14.61	23.41	19.68	2.67
China	11628	415829	110803.40	118672.2	9.55	309.37	83.85	88.19
India	1661	8853	4427.56	2492.20	1.70	7.19	3.84	1.90
Indonesia	40	533	252.75	145.13	0.20	2.18	1.11	0.58
Mexico	386	1065	596.75	195.86	4.01	8.85	5.45	1.40
Turkey	189	3885	1170.31	1191.66	3.18	53.07	16.73	16.25
South Africa	138	1003	757.19	278.34	3.22	21.58	16.27	5.88
European Union	98874	119259	107201	5627.32	202.77	244.45	216.95	11.12
Singapore	224	1056	594.5	224.25	61.02	203.72	133.87	38.74

I then examine and compare the effects of the independent variables on innovation in Singapore with the empirical evidence obtained from G20 countries. Infrastructure has a positive, statistically significant relationship with the number of resident patent applications in Singapore, which is consistent with the findings in previous studies. For example, Koh (2006) attributes Singapore's transition to innovation-based economic growth to changes in the technology infrastructure, economic institutions, and the incentives' structure. Based on the new Creative Productivity Index released by the Asian Development Bank and the Economist Intelligence Unit in 2014, Singapore is ranked first among 22 Asian economies on the level of creative inputs with respect to infrastructure, firm dynamics, and the governance of financial institutions. However, the city-state is less efficient to turn creative inputs into outputs, as evidenced by its ranking of 10th. The European Institute of Business Administration (INSEAD)'s Global Innovation Index ranks Singapore 7th on the level of inputs, but only 121st on the Innovation Efficiency Ratio[20] out of 142 countries. The effect of R&D spending on innovation in Singapore is not statistically significant in comparison with those in developed countries in the G20. On the one hand, Singapore depends heavily on foreign MNCs that contribute nearly 2/3 R&D spending. This partly explains why the average number of non-resident patent applications is about thirteen times greater than the number of resident patent applications in Singapore. On the other hand, Singapore's initial R&D spending mainly aimed to complement and support the operations of foreign MNCs in the 1990s. It began the shift to more strategic, longer-term projects (e.g., life sciences and pharmaceutical biochemistry) from the early 2000s. As indicated above, the effects of the level of economic development and FDI net inflows on innovation are not statistically significant in Singapore as a developed country.

[20] It is the ratio of the Output Sub-Index over the Input Sub-Index.

3.7 Conclusion

I measure the contemporaneous and one-period-lagged effects of the level of economic development, R&D spending, FDI net inflows, and infrastructure on innovation using a unique panel data set of 17 G20 countries and the EU as a whole for the period 1996-2011. Additionally, I examine and compare the innovation trends in Singapore with the empirical results in different country groups of the G20 to explore the determinants of innovation in Singapore. This essay highlights the economic importance of R&D spending and infrastructure relative to that of FDI net inflows and the level of economic development addressed in traditional studies. It also implies that routinely pooling developed and developing countries can result in misleading conclusions and inappropriate policy recommendations. Besides relying on infrastructure to promote innovation, Singapore ought to apply R&D and technology spillovers to domestic enterprises more efficiently.

Future research should be directed at including a broader set of independent variables if available, such as intellectual property rights and high-technology imports. For example, Schneider (2005) finds that the impact of intellectual property rights on innovation is positive in developed countries and negative in developing countries. She also finds that high-technology imports plays a more significant role in promoting innovation in developed countries than developing countries. I can extend her study by exploring the effects of these two factors on innovation in Singapore that is not included in Schneider (2005). Another direction for future research is to examine the interactions between nations within the same organization. For example, the amount of FDI inflows from Singapore's major trading partners (e.g., the U.S. and Malaysia) within the Trans-Pacific Partnership (TPP) instead of the total amount from the rest of the world may better capture inter-regional spillover effects. Additionally, I can analyze the varying importance of different types of patents over time and across countries.

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