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A Growth-Theoretic Empirical Analysis of Simultaneity in Cross-National E-Commerce Development

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A GROWTH-THEORETIC EMPIRICAL ANALYSIS OF SIMULTANEITY IN CROSS-NATIONAL E-COMMERCE DEVELOPMENT

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Abstract. The emergence of information and communication technologies infrastructure has transformed the global economy. The development of information technology infrastructure is limited to some developed countries though. This research explores the role of information technology infrastructure in B2C e-commerce growth at the country-level from the perspective of *growth theory* in economics. We propose a hybrid exogenous and endogenous growth model to explain e-commerce growth. We estimate a panel data model that incorporates the direct effects of e-commerce infrastructure and other key explanatory variables. We further specify a simultaneous effects model that permits the analysis of reverse causality in the association between e-commerce growth and Internet-based selling technology adoption. The data include 24 countries in four different regions around the world. We found that endogenous factors (online payment availability, and Internet-based selling technology adoption) and exogenous factors (international openness) both contribute to B2C e-commerce growth in a country. We also found that there is a two-way interaction between Internet-based selling technology adoption and e-commerce growth. The empirical findings support the effectiveness of our theoretical approach.

Keywords: Cross-national study, e-commerce, endogenous growth, exogenous growth, Internet, technology adoption.

1. INTRODUCTION

The emergence of information and communication technology (ICT) infrastructure has transformed the global and social economy. Although the rapid growth of the Internet has opened up opportunities for business in the developed and developing countries, the development of IT infrastructure and e-commerce, however, has been limited mostly to the developed economies. As a result, the disparity of e-commerce development across countries has been a crucial issue for the international organizations such as United Nations (UN) and Organization of Economic Cooperation and Development (OECD). These organizations have endeavored to help developing countries narrow the digital divide and increase their competitiveness by adopting information and communication technologies and e-business. There is an increasing amount of evidence from developed and developing countries that ICT access and use contribute to productivity growth, which is essential for supporting employment and income growth [33]. As a result, ICT infrastructure becomes a critical determinant of the growth of the information economy.

ICTs foster a broad spectrum of innovation activities which involve the individual, organizational, industrial, and national levels of economic productivity. At the national level, technological innovation contributes to productivity gains. Like previous technological upheavals, ICT innovations have profound consequences for the economy. ICT brings social and economic development and e-commerce activities create opportunities to alleviate the disparity between different levels of development [28, 29]. In the U.S., much of the acceleration of economic growth has been structural and attributable to ICT innovations and Internet technologies [25]. There is other evidence to indicate that ICTs accelerate productivity growth, but the impact of ICTs in e-commerce growth has still not been either theoretically or empirically nailed down. Realizing the power and advantages of ICTs, the UN and the OECD have investigated the role of ICTs and how they affect e-commerce development in developed and developing countries. The current lack of national-level statistics, measurement approaches, and appropriate theoretical frameworks inhibit our understanding of the interrelationship between ICT diffusion and e-commerce growth.

Previous studies have examined the cross-national level of e-commerce adoption and diffusion [10, 22, 36, 37, 38]. These studies investigate global e-commerce development from individual-level and organizational-level point of view. In contrast to these works, we employ a hybrid of exogenous and endogenous growth theory from economics to explain national-level e-commerce revenue growth and investigate the consequences of Internet-based selling technology adoption. Building on prior work in the literature, especially Ho et al. [16], in this research we intend to examine new questions which will push this research stream towards a consideration of the value of IT infrastructure in an economy relative to the growth of e-commerce. We ask:

- Does growth theory provide an appropriate theoretical base to explain B2C e-commerce growth at the country level? What factors does growth theory suggest will be important drivers?
- What role does Internet-based selling technology adoption play in the country-level B2C e-commerce development?
- Does the growth of B2C e-commerce also affect Internet-based selling technology adoption? Are there simultaneous effects and a feedback loop between Internet-based selling technology adoption and B2C

e-commerce growth?

- What can we learn from a large multi-year, cross-national data set about these issues? What kinds of models will be appropriate?

Our specific emphasis here, which goes beyond our earlier work, The remainder of the paper is laid out as follows. §2 reviews the exogenous and endogenous growth theories, and cross-national e-commerce studies. §3 presents our primary theoretical framework, a hybrid exogenous and endogenous growth theoretical model for e-commerce growth and proposed hypotheses. §4 introduces our data, variables, and data collection and sources. Then in §5 we present an empirical panel data model with the direct effect of technology adoption on B2C e-commerce growth. We perform a time-series cross-sectional analysis with feasible generalized least squares to address issues involving the violation of the standard assumptions. We also present the development and specification of a two-stage least squares model with instrumental variables and interpret the results. We assess the overall findings of the proposed growth models in §6. We conclude in §7 with contributions and limitations.

The main findings are as follows. First, from the various model estimations, we found that three factors, Internet user penetration, online payment tool availability, and Internet-based selling technology adoption, have positive effects on B2C e-commerce growth. Second, in a fixed-effects model, the exogenous driver, international openness, had a positive effect on e-commerce growth. Third, two-stage least squares regression also showed there are simultaneous effects between Internet-based selling technology adoption and e-commerce growth. In other words, Internet-based selling technology adoption contributes to higher e-commerce growth, just as e-commerce growth leads to more Internet-based selling technology adoption – a simultaneous relationship. By offering these kinds of results, this work is positioned at the leading edge of current empirical analysis approaches on the joint impacts of technology adoption on economic growth and economic growth on technology adoption.

2. LITERATURE

We next review the exogenous and endogenous growth theory perspectives, and discuss how the analysis of ICT infrastructure relates to cross-national e-commerce growth. We also provide the bases in the literature for the consideration of simultaneity, and a deeper consideration of cause and effect.

2.1. The Growth Theory Perspectives

Economic growth theory has been widely applied to study the economic performance of countries. *Exogenous growth theory* accounts for economic growth based on sustained technological advances, and stable interest rates on capital [17]. It assumes that technological change is exogenous—that is, externally-led, and not produced within an economy—the same technological opportunities are available everywhere, and that countries have closed economy systems. From this perspective, economic growth is the result of forces that affect an economy from outside of its economic system. Exogenous technological progress is a key determinant of long-term per capita output growth, for example. Growth will slow or even stop without technological progress. However, exogenous growth theory does not address some complicated issues that arise in the analysis of the production and diffusion of technology, knowledge, and information [1]. Exogenous growth theory also does not explain the outcomes when labor is considered as human capital or knowledge.

Endogenous growth theory argues that economic growth is the endogenous outcome of an economic system, instead of external factors [30, 31]. It has been applied in cross-national studies that involve the effects of technological diffusion on economic growth [12]. Cross-country differences in policies and preferences may lead to permanent differences in growth rates of per capita output. Endogenizing technology progress into the relevant input factors suggests that economic growth is a *two-way interaction* between technology and economy [1]. Technology is a form of capital accumulation, and adoption will differ in different countries. As a result, some endogenous growth models may be interpreted as models of technology adoption. Endogenous growth theory predicts the existence of positive externalities and spillover effects from the development of a knowledge economy [13]. Overall, the two theories provide contrasting but useful interpretations for studying the growth of e-commerce at the country level.

2.2. Cross-National Electronic Commerce

ICT adoption and diffusion across countries and the consequent impacts on the global information economy have generated interest among researchers and policy makers [4, 27, 28, 29]. Measurement challenges for ICT adoption, and evaluations of ICT impacts on the economy remain, however. They result from the lack of consensus about how measurement should be carried out, as well as the lack of sufficient comparable data at the national level for most countries [33, 2005]. The United Nations has used national-level Internet and mobile phone penetration, the trade of ICT-related goods, and e-commerce transactions as ICT adoption indicators [33, 2005 and 2006]. These statistics provide a picture of global ICT adoption and set up the analysis of ICT impacts on economic performance.

In the cross-national B2C e-commerce growth setting, technology adoption applies to two different levels: individuals and firms. Computers per capita, Internet user penetration, and ISDN subscriber penetration are primary

indicators for Internet technology adoption at the individual level. Human capital has been recognized as a critical factor of technology creation, adoption, and diffusion [Benhabib and Spiegel 1994]. Similar to the role of human capital in economic growth, Internet users in e-commerce prompt investments in Internet technology, more technology adoption, and additional e-commerce infrastructure. Internet users also support the growth of e-commerce transactions. Internet user penetration represents a key indicator for Internet connectivity. In 2005, for example, Sweden, Demark, the U.S. and Finland had over 90% Internet user penetration, which makes it likely that these four countries to have high consumer demand for e-commerce activities.

When a country ranks high on both Internet user penetration and secure server penetration, its e-commerce activities are likely to be highly active. For example, Iceland, the U.S., Canada, Demark, Netherlands, and Switzerland are countries with the most e-commerce activities, and these countries have ranked high on both Internet users and secure servers. In contrast, countries that rank low on Internet user and secure server penetration are likely to be slower e-commerce adopters. Less active e-commerce adopters include Mexico, the Slovak Republic, Turkey, Greece, Poland, Italy, France, and Belgium [25]. Overall, Internet user penetration and secure server penetration indicate of the extent of the infrastructure for e-commerce development in a country. [1]

3. THEORY DEVELOPMENT

We next develop our theoretical perspective to explain B2C e-commerce growth. We start by establishing a basic and direct relationship between technology adoption and e-commerce growth in a hybrid growth theory model. After that, we investigate a more complex set of interactions, and consider the possibility that there is a simultaneous relationship between Internet-based selling technology adoption and e-commerce growth.

3.1. A Hybrid Growth-Theoretic View

In this stream of research, we have previously argued that e-commerce growth may be endogenously-driven or exogenously-driven [16]—in other words, explained by forces that are internal or external to a country. In support of this view, we conducted an empirical test of drivers for e-commerce growth, including telecommunication investment intensity, venture capital, credit card availability, and education. Our evidence from seventeen European countries over the 2000 to 2004 period shows the different explanatory capabilities of our selected exogenous and endogenous precursors of e-commerce growth. However, we did not specify the role of technology adoption, which is a critical driver of B2C e-commerce revenue growth that will further enhance our understanding. In this study, we propose a hybrid growth-theoretic model for e-commerce growth that emphasizes the role of technology adoption.

A High-Level Conceptual Model. A hybrid growth-theoretic model is based on the idea that the forces of growth are both internal or endogenous, and external or exogenous to an economic system. We conceptualize a country as an economic system within which e-commerce growth occurs. The model can be specified as follows:

$$Y = \mathrm{f}(\alpha, X^{ENDOG}, X^{EXOG}, W, \varepsilon)$$

The variable Y represents B2C e-commerce revenue growth in a country, and X^{ENDOG} and X^{EXOG} are vector of endogenous and exogenous drivers. The specification also contains a time-specific parameter, α, and an error term. Also, W represents additional influences from the extent of relevant technology adoption for Internet-based selling technology. Consistent with our explanation, we handle technology adoption within this modeling formulation in two ways: (1) as a direct effect, so that the extent of technology adoption, W, is an explanatory variable for e-commerce growth; and (2) as an explanatory variable for e-commerce growth, an as an outcome in an economy that is influenced by the extent of e-commerce growth. The general idea is that it permits us to explore a relatively simple model (e.g., fixed-effects and random-effects panel data models). It also encourages the representation of greater complexity with technology adoption as an outcome explained by its own unique drivers, which, in turn, explain e-commerce growth, with other factors.

3.2. Modeling a Direct Relationship in Hybrid Model

Based on the proposed hybrid growth model, we specify a set of related hypotheses to explain national-level B2C e-commerce growth in terms of its key drivers.

Endogenous Drivers. Our arguments in support of the selected endogenous drivers in the hybrid model follow. First, human capital plays a special role in a number of endogenous growth models [2]. Human capital is recognized as a key input to country R&D, which generates the new ideas and products associated with technological progress [12]. Prior studies demonstrate that the average

[1] We previously explored the effects on e-commerce growth from a *leading country* to a *following country* [16]. Examples are Japan and Korea, or Canada and the U.S. We built an exogenous growth model to reflect this aspect, based on analysis that identified *potential leader-follower country pairs*. Here, we use a different approach. We will examine an exogenous driver, *international openness*, that codes for the potential co-movement effects of e-commerce growth. We will do this via a direct measure of the ratio of exports plus imports to gross domestic product (GDP) for selected most-likely leader-follower country pairs. The full explanation comes in §3.2. See Ho et al. [16] for the country-pairs definitions, and an overview of the alternative approach.

level of education [20] and the quality of human capital [8] are influential drivers for individual technology adoption. This leads to our first hypothesis.

- **Hypothesis 1 (The Adult Literacy Hypothesis).** *The greater the degree of adult literacy in a country, the higher the country's e-commerce growth.*

Second, the availability of online payment tools facilitates the growth of e-commerce [15]. To promote e-commerce, some countries have been enhancing their financial infrastructure through online transaction mechanism improvement and online payment tools. The adequacy of financial resources that consumers can bring to e-commerce is a supply-side driver that has been proven to have direct effects in shaping diffusion [33, 2003; 34]. Thus, we argue that the availability of online payment tools facilitates e-commerce growth. This leads to our second hypothesis.

- **Hypothesis 2 (The Online Payment Hypothesis)**: *Greater online payment system availability in a country leads to higher e-commerce growth.*

E-Commerce-Related Technology Adoption. The availability of online shops seems positively related to e-commerce growth in a country. However, cultural differences may moderate the adoption of e-commerce even though some countries have numerous online shops. For example, people prefer to shop in physical stores in France because of the personal intimacy. Secure server penetration is a proxy variable to measure the extent of Internet-based selling technology adoption. The major e-commerce uses of secure server software include encrypted credit card transactions in the online payment process and restricted access to privileged information within and between organizations. The encrypted credit card transactions mechanism reduces the transaction risks in the virtual market and increases the mutual trust between vendors and buyers [23]. The adoption of secure servers enhances transactional and environmental security in the digital marketplace. This leads to:

- **Hypothesis 3 (The Technology Adoption Hypothesis)**. *More adoption of Internet-based selling technology in a country leads to higher e-commerce growth.*

Exogenous Drivers. *International* openness represents an exogenous driver which captures knowledge spillovers from among countries that have the potential to influence interest in an economy. Coe et al. [9] and Keller [18] consider trade as a carrier of knowledge and assess the importance of imports in introducing foreign technology into domestic production and stimulate total factor productivity. The *degree of international openness* can be measured based on the ratio of exports plus imports to gross domestic product (GDP) [3]. The volume of a country's international trade is highly sensitive to country size. Large countries tend to depend relatively more on domestic in-economy trade. Dividing trade volume by GDP is a means to control for the size of the country, since population and surface area typically load on GDP. Further, e-commerce serves to reduce the importance of geographical boundaries, so international openness provides a meaningful measure of the degree of interdependence among countries.[2] Thus we propose that the degree of international openness is an exogenous driver of e-commerce growth, as a means to capture cross-national knowledge spillovers. Thus, we have:

- **Hypothesis 4 (The International Openness Hypothesis).** *More international openness in a country leads to higher e-commerce growth.*

Last, the number of Internet users is an important indicator of Internet connectivity and e-commerce access and demand [25]. Internet users reflect the potential market volume and may determine the extent to which technological innovations can be translated into profits or Internet-based sellers [38]. We treat Internet user penetration as a control variable.

3.3. Synthesis: A Full Model for E-Commerce Growth

Our hybrid growth-theoretic embedded technology adoption model for e-commerce growth model argues that the forces of e-commerce growth may be internal or external to a country. As we mentioned earlier, we will use simultaneous equations to model e-commerce growth and Internet-based selling technology adoption. We argue that Internet-based selling technology adoption is the dependent variable of the technology adoption function as well as an explanatory variable for the e-commerce growth function. Among the explanatory variables, we suspect that Internet-based selling technology adoption may have a non-recursive relationship with the dependent variable.

E-commerce transactions may stimulate the adoption of Internet-based selling technology. Zhu et al. [38] find that consumer readiness results in higher intent to adopt e-business practices. *Consumer readiness* refers to potential market volume and determines the extent to which innovations can be translated into profits. In our research context, B2C e-commerce transactions provide a proxy for consumer readiness. Therefore, we argue that e-commerce contributes higher Internet-based selling technology adoption and Internet-based selling technology adoption may increase e-commerce revenues. In the

[2] We have considered some exogenous drivers, such as international openness, population density, and foreign direct investment from the growth theory literature. We examined international openness only because most exogenous variables in economic growth theory may not be appropriate for the e-commerce context. International openness reflects the knowledge spillover effect across countries, which, in turn, represents exogenous technology adoption and diffusion among countries.

practice of business, it is very likely that these two variables have simultaneity and feedback loops.

4. DATA AND VARIABLES

4.1. Data Collection, Sources and Variables

Our dataset captures annual observations in 24 countries across four regions over the period 2001 to 2004. There are fifteen countries in Western Europe (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, and UK), two countries in Eastern Europe (Hungary and Poland), three countries in America (Canada, US, and Mexico), and four countries in Asia Pacific (Australia, Japan, Korea, and New Zealand). Data from different regions ensure that the sample is representative, even though we cannot claim it is complete. We obtained the data from international organizations, such as the International Telecommunications Union (ITU), the UN, the International Monetary Fund (IMF), UNESCO, and the OECD. We also obtained access to several private databases, including IDC/IDG, Jupiter Research, Mastercard, and the IMD World Competitiveness Yearbooks. [3] To ensure the accuracy and reliability of data, we validated the values of our variables by cross-checking them with different sources.

Our approach uses available national-level data to examine the relationship between e-commerce growth and related aggregated level variables. *B2C e-commerce* is defined as the value of products/services purchased by individuals. We adjust the dependent variable, B2C e-commerce revenues, by dividing by GDP to achieve a more effective scale for the variable. The independent variables include Internet user penetration, credit card penetration, education level, international openness, and Internet-based selling technology adoption. The latter is measured by secure server penetration, a proxy variable. We further model Internet-based selling technology adoption in a second function in terms of two variables: per capita e-commerce sales and venture capital availability. This is our embedded technology adoption model, and it permits us to test for simultaneity in infrastructure development and e-commerce growth.

Table 1 summarizes the variables, definitions, and data sources. Tables 2 and 3 show the descriptive statistics and pair-wise correlations of variables.

[3] Use of MasterCard data is appropriate to proxy for electronic payment system penetration in a country. It turns out that VisaCard data would work just as well, since these networks typically have similar degrees of penetration in most countries. The availability of credit cards in an economy is a good indicator for payment system infrastructure, according to by Mann [24] and Shaw [32], and other research from various Federal Reserve Bank economic research units in the United States.

Table 1. Variables, Definitions and Data Sources

VARIABLE	DEFINITION	DATA SOURCE
PerCapitaEC	B2C e-commerce expenditures / GDP; B2C e-commerce is the value of products or services purchased by individuals by clicking an order button on the Internet.	IDC, UN
NetUserRatio	Total number of Internet users / Population ages 15-64	Jupiter Research
CardPenetr	Number of master-card held / Population ages 15-64	Mastercard, UN
IntlOpen	(Export +Import)/GDP	IMF, UN
Education	Adult literacy rate	UNESCO, natl. stats
VCapital	Venture capital availability for business development, 1 to 10 scale	IMD World Comp. Yearbook, 2001-04
Servers	Number of secure servers / Population ages 15-64	OECD 2005/ Netcraft
TelcInv	Total capital invested in telecommunications /GDP	ITU

Table 2. Descriptive Statistics

VARIABLES	MEAN	MIN	MAX	STD DEV
PerCapitaEC	0.003	0.000	0.027	0.004
NetUserRatio	0.430	0.011	1.012	0.291
CardPenetr	0.636	0.000	2.547	0.291
IntlOpen	0.736	0.177	3.344	0.590
Education	94.703	58.01	99.900	7.718
VCapital	4.870	1.230	8.620	1.61
Servers	0.141	0.003	0.642	0.135
TelcInv	1.233	.000005	56.156	8.062

Table 3. Variable Correlations

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
NetUserRatio (1)	1						
CardPenetr (2)	.373	1					
IntlOpen (3)	-.263	.056	1				
Education (4)	.498	.311	.057	1			
VCapital (5)	.461	.297	.131	.431	1		
Servers (6)	.607	.433	-.262	.400	.410	1	
TelcInv (7)	.110	.095	.075	.157	-.092	.249	1

5. EMPIRICAL MODELS AND RESULTS

We next present a panel data model to identify the national-level factors of e-commerce growth, and develop our new modeling perspective on the simultaneity of ICT infrastructure and e-commerce growth in the economy.

5.1. A Fixed-Effects Regression Model and Results

In panel data regression, there are a number of tools that permit the analyst to control for omitted variables that differ between countries or regions but are constant over time, or that vary over time but are constant across countries or regions. We fitted models of the form:

$$\ln Y = \ln a + \beta \ln X + \ln v + \ln \varepsilon \qquad (1)$$

Here v is a country-specific residual and ε is the usual residual with the following properties: independently and

identically distributed with a mean of zero; uncorrelated with itself, X and v; and homoskedastic.

We have an adequate sample size but potential problems with heteroskedasticity for the sectors and serial correlation between successive years – in addition to the issue of endogeneity. We performed a number of basic model diagnostics. The pair-wise correlation coefficients between the explanatory variables are all lower than 80%, the criterion level suggested by Kennedy [19], where caution is necessary due to unstable parameter estimates. (See Table 3). The highest correlation is between Internet user penetration and secure servers at 60.7%. We further performed variance inflation factor (VIF) analysis and the VIFs of our explanatory variables all are less than 3, far less than the criterion level of 10 [19]. Thus, we find no evidence for multicollinearity.[4]

Our estimation equation is derived by extending a production function to this context:

$$\ln PerCapitaEC_{it} = \ln\alpha_1 + \beta_1 \ln NetUserRatio_{it} + \beta_2 \ln Education_{it} + \beta_3 \ln CardPenetr_{it} + \beta_4 \ln IntlOpen_{it} + \beta_5 \ln Servers_t + \ln v_i + \ln \varepsilon_{it} \quad (2)$$

We used the Breusch and Pagan Lagrange multiplier (LM) test [11] to examine whether a random-effects model is more appropriate than a fixed-effects model. The LM test ($\chi^2(1) = 75.04$, $p < .001$) shows that the variances of the country-specific errors are not equal to zero; this violates the random-effects model assumption. We further performed the Hausman [14] specification test to examine if the country residuals were uncorrelated with the other regressors in the model. This test suggested that the fixed-effects model is appropriate. Thus, we conclude that the null hypothesis of orthogonality should be rejected and chose the fixed-effects model.

The results of the fixed-effects model are presented in Table 4. Overall, the three variables (*CardPenetr*, *IntlOpen*, and *Servers*) have impacts on e-commerce growth. First, credit card penetration (*CardPenetr* = 0.379, $p <$ 0.075) is also a driver of e-commerce growth. Credit card penetration is a proxy for the availability of supporting payment tools. For example, in the U.S., 80% of Internet shoppers use credit cards to pay for their online transactions, while only about 50% do in other countries [21]. Some countries may not have as high a level of credit card penetration as we see in the U.S., and these countries should be more disadvantaged in terms of their ability to support e-commerce transactions, consistent with what we found. This supports our Online Payment Hypothesis (H2).

Table 4. Fixed-Effects Model Results

VARIABLES	COEF.	STD. ERR.	t-STAT.
NetUserRatio	1.278***	0.155	8.24
Education	38.756	28.668	1.35
CardPenetr	0.379*	0.210	1.81
IntlOpen	0.659*	0.357	1.85
Servers	0.553***	0.084	6.57

Notes: 96 obs., 24 countries, data from 2001-2004. Dependent variable: B2C e-commerce revenues divided by GDP. R^2 = 89.4%. Signif.: * = $p < 0.10$, ** = $p < 0.05$, and *** = $p < 0.01$.

We also found that the coefficient for secure servers is positive and significant (*Servers* = 0.553, SE = 0.084, $p < 0.001$). Secure server penetration represents the readiness and availability of online shopping environment. This shows that the more Internet-based selling technologies will be adopted, the higher e-commerce revenues will be in a country. It supports our Technology Adoption Hypothesis (H3). Finally, we found that our proposed exogenous driver, international openness, contributes to e-commerce growth (*IntlOpen* = 0.659, SE = 0.357, $p <$ 0.069). Such national-level knowledge spillovers may accelerate e-commerce related technology adoption among countries. This result implies that if a country has more trade interactions with the other countries, the country will tend to have more e-commerce revenues. It supports our International Openness Hypothesis (H4). Education, in contrast, did not have a discernible impact on e-commerce growth. This result bears further consideration. We used adult literacy to proxy for education level. The lack of a result may be due insufficient observed variation. The countries all had relatively high percentage levels for adult literacy. In addition, adult literacy rates tended to grow slowly every year among countries and did not show large temporal differences across our data.

5.2. A Feasible GLS Model and Results

Panel data-based empirical designs often violate the standard OLS assumptions. To address these issues, we further performed two post-estimations tests for serial correlation and contemporaneous correlation. We used the Wooldridge [35] test, whose results ($F = 30.251$, $p < 0.01$) indicate autocorrelation in the residuals of the panel data model [19]. This is reasonable because we have variables such as the number of Internet users, the level of education, the number of credit cards, trade volume, and the number of secure servers, which tend to be correlated over time. In such cases, a couple different regression approaches are appropriate. The approach we selected is *feasible generalized least squares* (FGLS) regression, which assumes that the regression errors are serially-correlated, usually as an AR(1) process with annual

[4] We also examined whether there is panel-wise heteroskedasticity, due to the different sizes of the countries and their economies in the pooled data. Although the exact relative error variances cannot be determined, it is commonly assumed that they vary inversely with the size of the sector [7]. We used the Breusch-Pagan test for heteroskedasticity, and determined that it is not an issue ($\chi^2 = 0.46$, $p > 0.49$) [11].

observations.[5] See Table 5.

Table 5. FGLS Regression Results

VARIABLES	COEF.	STD. ERR.	*Z*-VALUE
NetUserRatio	1.255	0.112	11.19***
Education	-3.503	5.729	-0.61
CardPenetr	0.184	0.047	3.92***
IntlOpen	-0.038	0.097	-0.39
Servers	0.348	0.053	6.55***

Notes. Model: FGLS. Correlation: panel-specific AR(1). 96 obs., 24 countries, 2001-2004. Dep. vars.: B2C e-commerce revenues / GDP. Wald $\chi^2(5) = 1017.4$***. Log- likelihood = 33.43. Signif.: * = $p < 0.10$, ** = $p < 0.05$, and *** = $p < 0.01$.

The FGLS regression results indicate that two variables *CardPenetr*, and *Servers*, have direct impacts on e-commerce growth. The coefficient of *CardPenetr* is also positive and significant (*CardPenetr* = 0.184, SE = 0.047, $p < 0.001$). This indicates that higher credit card penetration leads to higher e-commerce growth. The coefficient of *Servers* is positive and significant (*Servers* = 0.348, SE = 0.053, $p < 0.001$) also, which supports the Technology Adoption Hypothesis (H3). This means higher Internet-based selling technology adoption leads to higher e-commerce growth. The results we obtained were the same with the fixed-effects model in most respects. The International Openness Hypothesis (H4) was not supported by FGLS though.

5.3. Analyzing the Possibility of Simultaneity

To explore whether there are two-way interactions between Internet-based selling technology adoption and B2C e-commerce growth, we examine the simultaneous effects in the hybrid growth model. There may be reciprocal causation of e-commerce growth and Internet-based selling technology adoption. If there is endogeneity of an independent variable, it is inappropriate to directly estimate this regression.

Thus, we further examined whether a simultaneous equation model, which states that both e-commerce growth and Internet-based selling technology adoption serve as "cause" and "effect," would make sense. The simultaneous effects in hybrid growth are modeled as:

$$\ln PerCapitaEC_{it} = \beta_0 + \beta_1 \ln NetUserRatio_{it} + \beta_2 \ln Education_{it} + \beta_3 \ln CardPenetr_{it} + \beta_4 lnIntlOpen_{it} + \beta_5 \ln Servers_{i,t-1} + \ln \varepsilon_{it} \quad (4)$$

$$\ln Servers_{i,t-1} = \alpha_2 + \beta_6 \ln VCapital_{i,t-1} + \beta_7 \ln PerCapitaEC_{it} + \ln \xi \quad (5)$$

If all of the relationships are needed for determining the value of at least one of the endogenous variables, we have a simultaneous equations problem. The unique feature is that the dependent variable in one equation may be an explanatory variable in another. The problem then becomes that the dependent variable may be correlated with the error terms in that equation. *Two-stage least squares* (2SLS) extends regression to cover models that violate the recursivity assumption of OLS. 2SLS estimation examines whether there is feedback loop between Internet-based selling technology adoption and e-commerce growth. To implement 2SLS for the simultaneous effects test, we conducted the following steps. The first step is to regress the endogenous regressor on all of the exogenous variables in the system. The second step is to use an estimated instrumental variable, along with the included exogenous variables, to estimate the structural equations with OLS. Third, the estimated residuals are used to test for heteroskedasticity and autocorrelation. For simultaneity, we examined the possibility that *PerCapitaEC* and *Servers* are connected this way. To test this, we regressed all the exogenous variables in Equations 4 and 5. Table 6 shows the results.

Table 6. Simultaneous Equations Estimation Results

	B2C REVENUES MODEL (Dep.Var.: *PerCapitaEC*)			TECH. ADOPTION MODEL (Dep.Var.: *Servers*)		
Vars.	**Coef**	**SE**	***t*-value**	**Coef**	**SE**	***t*-value**
NetUser	-1.246	0.257	4.85***			
Edu	-14.09	5.421	-2.60			
CardPen	0.238	0.066	3.59***			
IntlOp	-0.07	0.106	-0.63			
Serers	0.367	0.164	2.23***			
PCapEC				0.600	.105	5.74***
VCapital				1.351	.424	3.65***
Model	$F(5, 90) = 66.42$*** Adj. R^2: = 77.0%			$F(2, 69) = 69.24$*** Adj. R^2: 68.0%		

Notes. 2SLS with 96 obs. in 1st and 72 obs. in 2nd model. 24 countries in both estimations. Data for 2001-2004 in 1st model and 2002-2004 for 2nd model, due to use of a lagged variable and loss of one year. * = $p < 0.10$, ** = $p < 0.05$, *** = $p < 0.01$.

From the embedded technology function, the results show that increasing venture capital results in higher Internet-based selling technology adoption (*VCapital* = 1.31, SE = 0.360, $p < 0.001$). In addition, the increase of e-commerce growth also results in higher Internet-based selling technology adoption (*PerCapitaEC* = 0.84, SE = 0.1127, $p < 0.001$). Meanwhile, the coefficient of *Servers* in Equation 4 is positive and significant with *PerCapitaEC* (*Servers* = 0.370, SE = 0.164, $p < 0.05$). These results indicate that e-commerce growth and the adoption of Internet-based selling technology have a positive feedback loop with each other. Internet-based selling technology adoption leads to higher e-commerce growth and e-commerce growth also leads to higher Internet-based selling technology adoption, a simultaneous relationship.

5.4. A Comparison of the Empirical Models' Results

[5] Beck and Katz [5] have written that FGLS can correct for any panel heteroskedasticity, which makes this attractive for our use. A second way is to use the *Parks-Kmenta approach* [26]. It combines assumptions on serial correlation, contemporaneous correlation and panel heteroskedasticity.

We further compared the differences among three models that we have examined. We found that the results of the FGLS and 2SLS estimations are qualitatively similar. The effects of *Education* and *IntlOpen* in OLS were different from those in FGLS and 2SLS. In FGLS and 2SLS, *Education* has negative effect on e-commerce growth. This result conflicts with the results in the fixed-effects model. The different results may come from different assumptions on the error terms in each model. FGLS and 2SLS assume that there is serial correlation, contemporaneous correlation and panel heteroskedasticity of errors. In addition, variables such as *Education* (adult literacy rate), and the ratio *IntlOpen* (exports + exports/GDP) may not have changed much during 2001 to 2004. To improve the model specification, it may be helpful to replace *Education* and *IntlOpen* with other e-commerce-related variables, such as computer literacy and international trade of ICT-related products. We were unable to collect these data from the international organizations, due to their unavailability at this time.

6. EVALUATION: PROPOSED THEORY, MODELS

We now assess the appropriateness of hybrid growth theory and the embedded technology adoption explanations for the growth of e-commerce. The proposed hybrid growth model for e-commerce intends to explore the endogenous and exogenous drivers of cross-national e-commerce growth. To gauge the impact of technology adoption in e-commerce growth, we highlighted the role of Internet-based selling technology adoption in the hybrid growth model. We handled Internet-based selling technology adoption in two different ways: (1) a *direct effect*, for which Internet-based selling technology adoption serves as an explanatory variable for e-commerce growth; and (2) *simultaneous effects*, for which Internet technology adoption and e-commerce growth reflect a two-way interaction.

In the direct effect estimation, the hybrid e-commerce growth model yielded good statistical fit in the fixed effects (R^2 = 89.4%) and FGLS models (Wald $\chi^2(5)$ = 1,017.4, log-likelihood = 33.43). The results in both models are generally consistent. In the fixed effects model, the endogenous drivers (*CardPenetr* = 0.379, SE = 0.210, $p < .075$; and *Servers* = 0.553, SE = 0.084, $p < .001$) and exogenous driver (*IntlOpen* = 0.659, SE = 0.357, $p < .069$) show positive effects on B2C e-commerce growth in a country. (See Table 4.) In the FGLS model, the endogenous drivers have the positive impacts on e-commerce growth (*CardPenetr* = 0.184, SE = 0.047, $p < .001$; *Servers* = 0.348, SE = 0.053, $p < .001$). (See Table 5.)

Our proposed models are able to capture the fundamental elements of B2C e-commerce growth across countries. The empirical results show that the hybrid e-commerce growth model successfully captures the direct effect of relevant technology infrastructure. Although we have tried to eliminate potential statistical problems such as correlated variables, multicollinearity, heteroskedasticity and serial correlation, there still may be issues with the data that we have not fully revealed. For example, education level was not explanatory in either the fixed effects model (*Edu* = 38.756, not significant) or the FGLS model (*Edu* = -3.503, not significant). (See Tables 4 and 5.) This may have resulted from the lack of changes in the education levels in most of the countries that we studied during the 2000 to 2004 period.[6] In addition, the exogenous driver for international openness (*IntlOpen* = -0.038, not significant) did not explain e-commerce growth in the FGLS model. (See Table 5.) This variable may not be perfect as a proxy exogenous factor to predict country-to-country co-movement in e-commerce growth.[7]

We further used the hybrid growth model to examine the more complicated relationships involving simultaneous effects. We applied 2SLS regression to examine whether there were two-way interactions between Internet-based selling technology adoption and e-commerce growth. Both equations yielded good levels of statistical fit (1st equation: adj. R^2 = 77.0%; 2nd equation: adj. R^2 = 57.9%). In the first equation, the endogenous drivers (*CardPenetr* = 0.238, SE = 0.066, $p < .001$; *Edu* = -14.09, SE = 5.421, $p < .01$; *Servers* = 0.367, SE = 0.164, $p < .001$) show significant effects on B2C e-commerce growth. In the second equation, B2C e-commerce growth (*PerCapitaEC* = -0.600, SE = 0.105, $p < .001$) and an alternative instrumental variable (*VCapital* = 1.351, SE = 0.424, $p < .001$) have positive effects on Internet-based selling technology adoption, and hence relevant infrastructure appears to play an important role. Overall, the hybrid growth model provides an appropriate theoretical basis for capturing the factors that are critical to the growth of e-commerce in a country. The theoretical model also suggests the different roles of IT infrastructure in national-level e-commerce e growth.

7. CONCLUSION

[6] In the overall context of an economy's GDP, B2C e-commerce will only represent a small portion of what is changing. Our education level measure represents the whole country's education too, which did not change much during 2002 -2004 for most countries. It may be more appropriate to use a measure of computer literacy (more specifically, familiarity with the Internet), instead of adult literacy. International openness poses the same issues: it is measured by (exports + imports)/GDP, which also may be too aggregated to capture the micro-effects on B2C e-commerce growth that we want.

[7] Although the availability of appropriate data is a limiting factor here, the kind of data that would be ideal for our analysis purposes is related to ICT investment levels, ICT exports and imports, government policies that related to investments in ICT, laws to promote e-commerce and e-commerce tax policy.

The development of ICTs has been recognized as an important factor of global economic development. The rapid growth of Internet technology opens up new opportunities for developing and developed countries. Although international organizations and governments have been investigating how to take advantage of ICT infrastructure to eliminate the digital divide, very limited empirical research efforts have been made to examine the impact of ICT infrastructure on e-commerce development. We now conclude with a discussion of the theoretical and practical contributions, and the limitations of this research.

7.1. Conclusions and Policy Implications

Our overall contribution is that we propose a theoretical model and empirically test the model to understand national-level of e-commerce growth. There are several theoretical contributions of this research. First, we introduce the economic theory of growth to explain national-level of e-commerce growth. We apply the idea of exogenous and endogenous drivers to develop a hybrid growth model which serves as a general theoretical basis to investigate cross-country e-commerce growth. The proposed hybrid exogenous and endogenous growth model explains the underlying mechanism for e-commerce growth across countries. Further, the hybrid growth model with embedded technology adoption allows us to understand the role of technological progress relative to e-commerce. This model also permits us to explore the complex simultaneous effects of cross-country e-commerce. Our results show that they interact with each other in a positive feedback relationship: increases in e-commerce growth are associated with the adoption of Internet-based selling technology, and the increase of Internet-based selling technology adoption will tend to accelerate e-commerce growth.

Policy-makers can benefit from the results of this study in three ways. First, we found that credit card penetration leads to higher e-commerce revenue, so a well-established financial infrastructure for e-commerce is beneficial for e-commerce development. Financial infrastructure includes the availability of online payment tools, and secure online shopping environment. Policies that create the basis for more efficient and more secure online transactions also have a positive impact on e-commerce development. Policies that are favorable to the development of telecommunication also accelerate Internet technology adoption and e-commerce development.

E-commerce development reflects the combined efforts of individuals, firms and governments. Among these efforts, however, government policies appear to dominate the direction and speed of e-commerce development in a country. If governments in developing countries can establish effective financial and telecommunication infrastructures, these policies will encourage firm-level and individual-level of e-commerce adoption. Therefore, the developing countries should take advantage of the experience from more developed ones. They should promulgate policies that speed up the development of financial and telecommunication infrastructure. Such policies, over the longer term – and in association with other fundamental advances in their economies – will help developing countries to enhance their e-commerce development.

7.2. Limitations

We note a number of limitations of this cross-country study. Our data are primarily taken from developed countries across a relatively short time horizon, with less representation of the developing countries. Combined with the limited number of data points that we have, the reader should recognize the limits to the generalizability of our findings. For some variables, we have not been able to collect complete data. These missing data constrained our ability to include some countries. Second, the measurement of data by international organizations and consulting firms may not have been done in the same manner, and there may be apples-and-oranges comparison issues. Collecting data at different times of a year (e.g., different fiscal year-ending dates) may also make it problematic to fully leverage the value of our data. Moreover, international organizations may not collect data that are just right for our study, since they have their own agendas for data collection and different degrees of sensitivity to the actual costs of data collection. We did not consider government policies related to taxes on e-commerce businesses, the promulgation of telecommunications and Internet access standards, and the control of Internet fraud. It is challenging to evaluate the impacts of government policy in a quantitative manner. *Post hoc* qualitative evaluation may be the most revealing. The limitations suggest an opportunity to refine our results to increase their relevance for more countries in the different regions around the world.

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