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EXPORT PERFORMANCE OF THE ASIAN MIRACLE ECONOMIES: THE ROLE OF INNOVATION AND PRODUCT VARIETY

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Abstract: Traditional export models fall short of explaining the marked increase in exports of the Asian miracle economies in the post-WWII period. A model showing that exports are driven by innovations, innovative competitiveness, demand, and price competitiveness is estimated for China, India, Korea, Japan, Singapore and Taiwan over the period 1953-2010. The results demonstrate that innovation stocks and competitiveness are important determinants behind their success. Furthermore, innovation stocks and innovative competitiveness are shown to be less influential for export growth in China and India and their export booms have been fueled by process rather than product innovation.

JEL Classifications: O30, O40

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1. Introduction

An important feature of the economic success of the Asian miracle economies (China, India, Japan, Korea, Singapore and Taiwan), henceforth the AM economies, has been their ability to sustain high export growth over a long period of time. Their export performance has been remarkable. Exports as a percentage of GDP grew more than 500% in the period 1970-2010 for China and 72% for the AM economies as a whole. This stands in sharp contrast to the experience of the sub-Saharan African economies where exports grew by only 1.5% over the same period (see the online appendix, section E, for data sources). Given that changes in external conditions have not been much more favorable for the AM economies than for the African economies, this suggests that we need to look beyond simple explanations of cost competitiveness and external demand.

Despite the unprecedented export growth performance of the AM countries over a very short time span and the considerable attention given to this issue in the literature, very little research has attempted to examine the underlying approximate causes of their strong export growth. Redding and Venables (2003) and Jongwanich (2010) are among the few exceptions. Specifically, Redding and Venables (2003) decompose export growth into the contribution of foreign market access and the improvement of supply conditions whereas Jongwanich (2010) estimates an imperfect substitution model in which export volume is taken as a function of real exchange rates, world income, production capacity and foreign direct investment.

Furthermore, trade and growth theory has evolved considerably in the last two decades and offers a number of alternative explanations for the export success of the AM economies. These include explanations based on governance, infrastructure, educational attainment and those based on R&D, innovation, increasing specialization, and new goods. With respect to trade and growth in particular, an extensive literature following Helpman and Krugman (1985) and Grossman and Helpman (1991) emphasizes the importance of new goods and trade in intermediate goods as sources of growth. In these models trade in intermediate varieties of goods generates specialized inputs into production processes. But very little evidence exists concerning how these theoretical links explain the trade booms in the AM countries.

In this paper we aim to evaluate whether these theories that emphasize the importance of new goods and innovation in explaining trade, can help in understanding the proximate sources of the massive export booms in the AM economies. Specifically we aim to exploit the extensive international data that exist on trademarks, product designs, patent stocks and R&D investment to see if the innovations they capture may have played a major role. It should be highlighted that direct measures of innovation are not available. We therefore use R&D and patents as proxies for quality-improving innovation whereas trademarks and product designs as proxies for product variety. We supplement these data with other variables such as governance and institutional measures to give a more comprehensive investigation of complementary explanations for the growth in trade of the AM economies, and consider differences between the early miracle economies such as Japan and Korea, and the newly emerging giants of China and India. The research in this paper is the first to study exports in the AM economies within an innovation and growth framework.

To motivate our empirical specification we first derive a standard trade-in-varieties model in which innovations and innovative competitiveness are incorporated.

This goes one step further than the traditional trade theories where exports are driven primarily by foreign income and price competitiveness (see, for critical assessments of traditional income-based models, Krugman (1989), Fagerberg (1994, 1996), Wolff (1995), Anderton (1999a, b), Fagerberg et al. (2007) and Madsen (2008b)). The model is tested using data for stock of innovations, innovative competitiveness, price competitiveness, and foreign income for six AM economies over the period 1953-2010.

Empirically, the model is in the same spirit as the papers that have integrated R&D into trade models for OECD countries. In an influential paper, Fagerberg (1988) shows that innovative competitiveness, measured by relative R&D expenditure and patent counts, has important effects on aggregate exports for OECD countries. These results have been extended and supported by the findings of Amendola et al. (1993), Magnier and Toujas-Bernate (1994) and Amable and Verspagen (1995) based on pooled cross-section and time-series data for OECD countries. Using sectoral data, a number of studies have also examined the effects of innovative competitiveness on sectoral market shares and trade (see, e.g., Greenhalgh (1990), Greenhalgh et al. (1994), Magnier and Toujas-Bernate (1994), Fagerberg (1997), Anderton (1999a, b) and Carlin et al. (2001)).

The paper proceeds as follows. The theoretical model, which is used to motivate the empirical analysis, is derived in the next section and empirical estimates are carried out in Section 3. Section 4 presents robustness tests and further empirical analysis and Section 5 concludes.

2. A Simple Model of Research Activity and Trade

In this section we first illustrate the relationship between R&D investment and export supply that arises in a standard product variety model. The model shows that innovations can affect exports through either cost savings on existing goods or in the form of discovery of new goods. Though the setting is very standard, the model provides a parsimonious link between traditional empirical export models, such as those surveyed in Goldstein and Khan (1985) that focus on income and price as determinants of exports, and the newer theories that focus on the role of innovations in the growth process.

2.1 Demand for intermediate goods.

Trade flows consist of both intermediate and final goods and the latter have become increasingly important over time, and especially in Asia (Puga and Treffler, 2010; Hanson, 2012). To fix ideas we therefore describe a simple model of trade in intermediate goods. This provides a tractable way of exploring the links between trade, productivity growth and also R&D or innovation activities.[1]

Thus, consider a representative firm in country, *i*, that produces final goods using labor, L_i, and intermediate goods designated by source country *j*, x_{ij}. Following Ethier (1982) and Helpman and Krugman (1985) we assume further that *i* has a production function given by:

$$Y_i = AL_i^{1-\alpha} z_i^{\alpha} , \tag{1}$$

where A is total factor productivity; $z_i \equiv (\sum_{j=1}^{M} N_j x_{ij}^{\alpha})^{1/\alpha}$ is an aggregate intermediate input index; M is the number of countries in the world economy; N_j, is the number of patented intermediate products produced in country *j*, and $\alpha < 1$ is a parameter.[2] As in the growth literature, such as Romer (1990) and Rodrik (1996), z_i is an index of productivity in the final goods sector in *i*, which in turn is a function of the number of varieties of intermediate goods used in country *i*. Likewise N_j, is an index of the research and development intensive output of country *j*. Hence, in this simple Ethier-Romer framework, the productivity in final goods and the innovation intensity of exports are both directly linked to the number of traded intermediate varieties.

The firm's input demand choice for a unit of intermediate goods is

$$x_{ij} = \alpha\left(\frac{Y_i}{P_i}\right)\left(\frac{p_j}{P_i}\right)^{-\sigma} \tag{2}$$

where $\sigma = 1/(1-\alpha) > 1$ and $P_i \equiv \left(\sum_{j=1}^{M} N_j p_j^{1-\sigma}\right)^{1/(1-\sigma)}$ is a price index for aggregate intermediate input z_i. Eq. (2) is a standard import demand equation and is widely used in the gravity model in international trade literature (Anderson, 2011). It shows that country *j's* exports depend on the total intermediate demand effect from the destination country, $\alpha Y_i / P_i$, and the price competitiveness effect $(p_j / P_i)^{-\sigma}$. If $\sigma > 1$ then a reduction in the relative price of country *j*'s intermediate goods exports relative to other countries will result in an increase in export sales for country *j*. [3]

2.2 R&D Sector

We wish to investigate the role of research and development in the exporting country, and in particular on its supply of exports. Following, for example, Romer (1990), and Grossman and Helpman (1991), and more recent models such as Gustafsson and Segerstrom (2010), we assume intermediate-product-producing firms design and patent new intermediate goods under conditions of monopolistic competition. We assume that an intermediate good produced in country *j*, x_j costs $\gamma_j \geq 1$ units of output to produce. Producer *j*'s profits at a point in time are given by the profit per unit sold to firms in all *M* countries. Profits are given by $\pi_j = (p_{ij} - \gamma_j)\sum_{i=1}^{M} x_{ij}$. It can be shown that the profit maximizing price for all goods produced is equal to $p_{ij} = p_j = \gamma_j / \alpha$. Using this equilibrium condition, multiplying both sides of (2) by N_j, and taking logarithms, gives a simple linear export equation that depends on import demand and export supply parameters,

$$\ln X_{ij} = (1+\sigma)\ln\alpha + \ln(Y_i / P_i) - \sigma\ln(\gamma_j / P_i) + \ln N_j \qquad (3)$$

where $X_{ij} \equiv x_{ij} N_j$ is total exports from *j* to *i*.

Eq. (3) summarizes the impact of R&D in the exporting country on its exports. Clearly $\partial \ln X_{ij} / \partial \ln N_j > 0$ and $\partial \ln X_{ij} / \partial \ln \gamma_j < 0$. Hence there are two types of technological change that can increase country *j's* exports. The first is a reduction in γ_j / P_i, which implies increasing the competiveness of its R&D sector. In addition there is a size effect through expanding the number of varieties the export country produces, N_j.

Traditional empirical models of export behavior, as in Goldstein and Khan (1985), include price competitiveness as an argument but not knowledge or R&D. Eq. (3) shows, however, that price competitiveness may reflect elements of R&D or knowledge competitiveness, to the extent that they reduce the relative price of intermediate traded goods, γ_j / P_i. This type of R&D might be thought of as product development through imitation, which is a feature of innovation in transitional and developing countries.

Nevertheless trade theory suggests that both incremental imitation type knowledge and the development of new goods are important (Grossman and Helpman, 1991; Gustafsson and Segerstrom, 2010). Moreover innovation in low wage economies often takes the form of product and process quality upgrades. Such changes may not easily be captured in price data since they involve changes in the quality of components.

Furthermore, Puga and Trefler (2010) show that innovation in new goods, such as an expansion in varieties, N_j, is becoming increasingly important for AM countries especially Malaysia, Thailand, India, the Philippines and China. Thus, innovation activities such as R&D spending and knowledge stocks, as indicated by Eq. (3), are important factors to consider in our empirical investigation into the AM countries export performance.[4]

3. Empirics

Eq. (3) suggests that we can augment traditional export models based on trade-weighted income (TWI) and price competitiveness by including supply side measures of innovative activity. Specifically it suggests the following empirical counterparts:

$$\ln EX_{it} = \alpha_0 + \alpha_1 lnTWI_{it} + \alpha_2 lnP_{it}^{ex} + \alpha_3 lnSTK_{it}^{x} + CD_i + \varepsilon_{1,it}, \tag{4}$$

$$\ln EX_{it} = \beta_0 + \beta_1 lnTWI_{it} + \beta_2 lnP_{it}^{ex} + \beta_3 lnCOM_{it}^{x} + CD_i + \varepsilon_{2,it}, \tag{5}$$

$$x = RD, PS, TM, PD \ or \ PC$$

where *EX* is total export volume, *TWI* is trade weighted real income of export destination countries, P^{ex} is export price competitiveness, *CD* represents a set of country dummies, ε is a stochastic error term, COM^{x} is innovative competitiveness for the innovative variable x, STK^{x} is domestic innovation stock for the innovative variable x. Innovation knowledge and innovative competitiveness are based on R&D stock (*RD*), stock of patent applications (*PS*), stock of trademarks (*TM*), product designs (*PD*) and their first principal component (*PC*).

We estimate Eqs. (4) and (5) using panel time series data for the AM countries in the period 1953-2010. The innovation knowledge stock and innovative competitiveness are included separately in the trade model because they are highly correlated. The correlation between the two variables ranges between 0.73 and 0.83, suggesting that most of the identifying correlation in innovative competitiveness comes from the variation in the innovation stock among the AM economies. A financial crisis dummy variable

(1997/98 = 1 and 0 otherwise) was initially included in the regressions for Japan and Korea; however, it was dropped from the final regressions because it was insignificant.

Knowledge is based on various measures of innovation such as R&D, patents, trademarks, and product designs because they each represent different attributes of innovative activity. In addition to using the individual measures of innovation stock, these indicators are also combined into a composite index using the method of principal component analysis which seeks to find patterns in data of high dimension as in our case. Principal component analysis is a powerful way of highlighting differences and similarities in the data and compresses the number of dimensions substantially without the loss of information. In principal component analysis all variables are first standardized so that they represent deviations from the mean divided by the standard deviation to ensure that they have the same mean and standard deviation. Using information from the leading eigenvector from the decomposition of the covariance matrix of the variables as weights, the resulting composite index is then constructed as a linear combination of the original innovation indicators.

The principal component is, particularly, suited for the analysis in this paper because of a high correlation between the innovation variables. The composite index for innovation stock is significantly positively correlated with all indicators of innovation stock, with correlation coefficients ranging from 0.77 (product design stock) to 0.95 (trademarks stock), thus suggesting that it is an appropriate measure of overall innovation stock. For innovative competitiveness stock, the correlation coefficients range from 0.60 (R&D competitiveness stock) to 0.90 (trademarks competitiveness stock). The empirical estimates are very similar if the simple average is used instead.

3.1 Estimators

Eqs. (4) and (5) are estimated using the instrumental-variable fixed-effect (IV-FE) estimator. This procedure corrects for possible endogeneity due to reverse causality, measurement errors and omitted variable bias, and is used as our benchmark estimator. To provide robustness checks for the results, the above equations are also estimated using the vector-error correction model (VECM) and the group-mean panel fully-modified (FM-OLS) estimator. The VECM is a dynamic system approach that treats all underlying variables as endogenous. This approach assumes that all variables are directly measured without errors. Hence, while it allows for the possibility of reverse causality it does not deal with measurement errors. Country dummies are not included in the estimations using VECM. Given that the OLS estimator is asymptotically biased and inconsistent, we also use the between-dimension FM-OLS estimator of Pedroni (2000), which applies semi-parametric correction to the OLS estimator to eliminate bias due to endogeneity of the regressors. A detailed description of these procedures is provided in the online appendix (Section A).

3.2 Identification

Instruments are used for the innovative competitiveness, innovation knowledge stock, and price competitiveness as the parameter estimates are likely to be influenced by endogeneity and measurement errors. For price and innovative competitiveness this implies that instruments need to be created for the home country as well as competitors, where the competitors are not just the AM economies but also the western OECD countries. Altogether this adds up to 26 countries, where the countries are listed in the first paragraph of Section 3.3. The required large number of instruments may partly explain why external instruments are rarely, if ever, used in empirical models of foreign trade. In this subsection we first discuss the reason why it is necessary to use an instrument strategy and then discuss the instruments that are used for identification.

There are several reasons why an OLS estimation strategy may lead to biased coefficient estimates. First, for innovation stock and innovative competitiveness the coefficient estimates may be biased in OLS estimates due to unobserved country characteristics that are correlated with the included covariates. For example, exports in the AM countries may partly have been fuelled by a more market-oriented and open approach to foreign trade and innovation that has simultaneously enhanced productivity growth and exports. Second, slow export growth, for example, may be associated with increasing unemployment that, in turn, reduces wage growth through the Philips curve effect and, consequently, leads to an improvement in export price competitiveness. Third, increasing demand for exports will simultaneously increase the price and volume of exports; thus establishing a perverse relationship between exports and price competitiveness. Fourth, Madsen (1999) shows formally that export price elasticities are asymptotically biased towards -1 and not zero, as conventionally believed, due to measurement errors in decomposing export values into prices and quantities. Export volume is almost always measured in units of weight, which implies that a transition from exporting, say, cast iron to selling highly technological and sophisticated products, *ceteris paribus*, reduces export volumes even if quality adjusted exports are unaltered and, by default, increases prices proportionally. Thus, although price competitiveness has not been reduced the decompositional measure error will force the coefficient of price competitiveness towards -1.

Four external instruments are used for identification. Real food prices and unionization are used as instruments for price competitiveness while cohort infant mortality and temperature are used as instruments for innovation stock and innovative competitiveness. Food prices and unionization (union members divided by employment) are used as instruments for export price competitiveness, P^{ex}, since output prices, and hence export prices, are predominantly driven by markups on unit labor costs, which in turn are determined by wage push factors through the Phillips or the wage curve. Prices of food deflated by consumer prices and unionization are considered to be among the most important wage push factors (see Bruno and Sachs, 1985; Madsen, 1998b, 2009a). Although unemployment is a central variable in the Phillips curve it is not included in the instrument set because it, through the natural rate framework, is determined by wage push factors and, as such, is not exogenous (Madsen 2009a).

Relative food prices affect output prices directly because wages, formally or informally, are indexed to consumer prices. The food price shocks in the 1970's are examples of commodity price shocks that, in conjunction with increased unionization, triggered inflation during the 1970's and in the first half of the 1980's. Measuring the wage pushiness by the wage gap (the real wage in excess of labor's marginal productivity), Bruno and Sachs (1985) show that there is a close relationship between the wage gap and union membership rates. Thus, unions are associated with high union membership, as demonstrated by a marked increase in union membership prior to and during the wage explosion period in Europe in the 1970's (Bruno and Sachs, 1985;

Madsen, 1998b). Conversely, wage explosions were not experienced in countries such as the US, Singapore and Switzerland where unionization did not increase. Over the past two decades union membership rates have slipped in the non-AM economies while they have increased in China, Singapore and India and decreased slowly or stagnated in the other AM countries; thus, giving large identifying variations in the data.

Taxes (tariffs, direct taxes and indirect taxes) and real oil prices were initially included as instruments for price competitiveness. Taxes are, in some union models, also considered potential wage push factors since workers may seek compensation through higher wages to cover the deterioration of their real disposable income in response to higher taxes (Goerke, 2002). Bruno and Sachs (1985) argue that real oil prices are important wage push factors because of their effect on the cost of living. However, we excluded taxes and real oil prices from our instrument set because they were insignificant and because we wanted to keep the first-round regressions as parsimonious as possible. Furthermore, taxes are not entirely exogenous but influenced by the state of the economy. The insignificance of taxes is not surprising since many AM economies have recently introduced a tax system that is comparable with that in the mature OECD countries and also because higher taxes do not necessarily drive wages up in some union based models (see, for example, Goerke, 2002). The insignificance of real oil prices may reflect an intricate system of fuel taxes and subsidies and, more importantly, that oil price shocks, in the absence of taxes and subsidies, will affect all countries almost equally and, therefore, not influence price competitiveness.

Relative food prices as well as union membership rates are likely to be exogenous. They are determined by domestic and international food supply shocks, which are heavily influenced by exogenous weather conditions such as droughts and floods. Since the composition of food consumption differs across nations and a large fraction of food is domestically grown, food prices, in contrast to oil prices, move quite independently across countries. Regarding union membership, there is a large literature showing that social customs, pro-union attitudes, and the fraction of the electorate supporting left-wing parties are crucial determinants of unionization (Goerke and Pannenberg, 2004). This explains the intuition that the wage explosion in the 1970's was very much influenced by a pro-labor social movement that was very strong in many western countries. As social customs and political attitudes are unlikely to influence exports through channels other than unionization the exclusion restriction that union membership influences exports through price competitiveness is highly likely to be satisfied.

The stock of innovations and innovative competitiveness are instrumented using temperature and cohort infant mortality rates as primary instruments (the wage push factors are also used as instruments since we are using 2SLS). Temperature anomaly serves as a potentially good instrument in that persistent low temperatures may create hunger and starvation in low income countries, such as the AM economies during the 1950s. A small reduction in temperature is often associated with a reduction in the duration of light during the year and, consequently, with a reduction in the growing periods of crops and pastures and the ability to cultivate land at high altitudes. Malanima (2006), for example, finds climate to have been influential for living standards in Europe during the past millennium. Temperature can potentially influence innovations in that R&D is likely to be the first to suffer if income is reduced due to weather conditions.

Cohort infant mortality, Φ, is a potentially excellent instrument for innovations because, as explained below, it proxies the cognitive ability of the working population conditional on their health experience during their fetal life and infanthood noting that most of the cognitive development reached at adulthood occurs *in utero* and in the early years after birth (Eppig et al., 2010; Madsen, 2013). Following Madsen (2013) cohort infant mortality is constructed as:

$$\Phi_t = \left(\sum_{j=15}^{64} Pop_{jt} IM_{t-j}\right)(Pop_{15-64})^{-1}, \qquad j = 15, 16, \ldots 64 \qquad (6)$$

where Pop_{jt} is size of the population in age cohort j at time t, $Pop_{15\text{-}64}$ is the population of working age, and IM_{t-j} is the infant mortality rate at period t-j. This equation shows that the working population cohort at time t comes from a birth cohort in which the average infant mortality was Φ. For the 25 year old cohort, for example, Φ is the infant mortality of the population 24 years earlier. Since the estimation period commences in 1953 cohort infant mortality is constructed from data spanning 1890-2010.

Why is cohort infant mortality so important for innovations? The key here is that cognitive skills, which are vital for knowledge production, have been shown to be highly sensitive to health insults in utero and the early years of life; particularly health insults such as parasitic and infectious diseases (Eppig et al., 2010). Since most of the brain's development occurs from half way through pregnancy until the child reaches the age of two, this period is by far the most important for cognitive development and health capital in general (Niehaus et al., 2002; Almond and Currie, 2011**)**. Adequate development of the brain during infancy requires a sufficient supply of energy, essential micro nutrition and oxygen, noting that the brain in a new-born baby claims at least 87% of the body's energy budget (Holliday, 1986). Numerous studies have shown that parasitic and infectious diseases significantly impair cognitive ability and development due to loss of appetite, mobilization of the immune system, diarrhoea, and, loss of tissues to parasites (see Watkins and Pollitt, 1997; Jardim-Botelho et al., 2008).

Increasing cognitive skills, as signified by decreasing cohort infant mortality, is likely to have been a potentially important determinant of the increasing innovative activity in our country sample in the period 1953-2010. In this context it is important to note that IQ's are not fixed over time and across nations as is commonly and implicitly assumed in the literature on endogenous growth and human capital. The psychological literature finds that IQ's in the western world have on average increased by approximately three points in each decade over the past century (Lynn and Vanhanen 2006); thus it has significantly increased the research potential of western countries since 1953. Cohort infant mortality data are used as proxies for IQ following Madsen (2013) because the available IQ data are highly fragmented and no continuous macro data exist over a long time-span for the sample countries used here.

Cohort infant mortality is likely to be exogenous since it is computed from infant mortality rates in the distant past and it is unlikely that factors that caused the decline in infant mortality rates have simultaneously impacted on exports with a lag. The decline in infant mortality is predominantly due to improved sanitation, introduction of water supply and sewage infrastructure and pasteurization of cow's milk (Lee, 2007; Castilho and Barros Filho, 2010). These factors have improved quite independently of the promotion of exports and modernization. Pasteurization and the extensive expansion of the sewage and water supply infrastructure, for example, started in the late 19th and early 20th centuries in Europe and the US (Lee, 2007; Castilho and Barros Filho, 2010); however, the level of per capita income was quite different across these countries in that period and, more importantly, trade, in proportion to GDP, contracted or stagnated in the period 1914-1960 during which time infant mortality decreased the most (Madsen, 2009b).

The instruments for price and innovative competitiveness are constructed using bilateral weights in the same way and non-instrumented innovation and price competitiveness, as shown explicitly in the next sub-section.

3.3 Data

The trade weighted income for country *i* refers to the GDP of the destination country *j* weighted by the share of nominal exports from country *i* to country *j* at year *t* as follows:

$$TWI_{it} = \sum_{j=1}^{26} \frac{Ex_{jit} Y_{jt}}{Ex_{it}}, \qquad i \neq j, \tag{7}$$

where Ex_{ji} is nominal exports from home country *i* to country *j* in common currency (USD), Ex_i is total nominal exports of country *i* in common currency, and *Yj* is real income of the destination country *j*. Data for the following 26 countries are used to construct the index: Canada, the US, Japan, Australia, New Zealand, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the UK, Singapore, Taiwan, South Korea, India and China.

Innovation stock is measured by patent stock, real R&D stock, stock of trademarks and stock of product designs, following the predictions of innovation-based models. While R&D and patents are more related to quality-improving innovation, trademarks and product designs are more closely associated with product variety. Following Coe and Helpman (1995), R&D expenditure is deflated by an unweighted average of the economy-wide value-added price deflator and an hourly earnings index. The stock of knowledge is constructed using the perpetual inventory method with a 15% depreciation rate. The initial stock of knowledge is inferred from the flow of knowledge by dividing initial flow of knowledge by the sum of the rate of depreciation (15%) and the average annual geometric growth rates in real knowledge flow over the entire data period. Patents, trademarks, and product design data are based on the number of applications filed by domestic residents. Applications instead of grants data are used because the granting period varies substantially over time and across countries (Griliches, 1990).

Price competitiveness is constructed using bilateral weights as follows:

$$P_{it}^{ex} = P_{it} / \sum_{j=1}^{26} \frac{Ex_{jit} e_{ijt} P_{jt}}{Ex_{it}}, \tag{8}$$

where P_i and P_j are export unit values (export prices) of country i and j, respectively, e_{ij} is the bilateral exchange rate between country j and i, where an increase in e signifies a currency depreciation of country *i* vis-à-vis country *j*.[5] An increase in P^{ex} is associated with a deterioration of country *i*'s price competitiveness.

Technological competitiveness is also based on bilateral trade weights and is constructed as follows:

$$Com_{it}^{x} = S_{it}^{x} / \sum_{j=1}^{26} \frac{Ex_{jit} STK_{jt}^{x}}{Ex_{it}}, \tag{9}$$

where STK^x is the stock of innovations (*x* = RD, PS, TM or PC). An increase in the index is associated with an improvement in innovative competitiveness.

[Insert Table 1 here]

Table 1 presents the geometric growth rates of all variables used in the regressions. The data confirm that the AM countries have experienced marked increases in export volume and that these growth rates have been associated with equally impressive increases in the innovation stock variables as well as knowledge competitiveness. The approximately 10% increase in R&D and patent stock has, on average, resulted in a remarkable 6% (approximate) improvement in knowledge competitiveness. This implies that R&D and patent stock among the AM economies have increased substantially. The increase exceeds that of the mature OECD economies and may potentially explain the export success of the AM economies. Finally, the growth rates in both trade mark and product design competitiveness have been less impressive than the increase in patents and R&D.

To put the export growth of the AM economies into perspective Table 2 displays the growth of real exports for the world decomposed into country groups over the period

1950-2010 following the IMF's country classification. In this period world exports have increased 6.1 % annually, which is about half of the growth experienced by the AM economies. The only country group that has experienced an export trajectory similar to the AM economies is the European developing countries which, predominantly, consists of the Eastern European states.

[Insert Table 2 here]

3.4 Graphical analysis

Figure 1 displays the growth in exports (EX), trade-weighted income (TWI), export price competitiveness (EPC), innovation stock (STK), and innovative competitiveness (COM) for each country in the group of AM economies. The knowledge stock is based on the stock of patents. All variables are measured in annualized growth rates over 5-year periods to smooth out annual fluctuations.

[Insert Figure 1 here]

The figure confirms the well-known fact that the AM economies have experienced spectacular export growth rates in the post-Korean War period. Growth rates were very high in the 1960's and 1970's for Japan, Korea, Singapore and Taiwan and, that there has been similarly high growth for China since the late 1970's and acceleration in India's growth since the mid to late 1980's.

However, these export growth profiles do not accord well with the growth in trade-weighted income. The figure shows that the income growth rates among their trade partners have been much slower than exports for each of the AM economies. Trade weighted income has been increasing, on average, at the rate of 3.5% per year since 1953, which is not extraordinarily high when it is taken into account that the income data are not measured in per capita terms, and is clearly much below the growth of exports. Furthermore, trade-weighted income has grown at almost the same rate for all the AM economies and, as such, does not explain their different timing of export growth spurts, although it cannot be ruled out that trade-weighted income has been influential for the trend in exports. On the whole, the growth rate of trade-weighted income does not tend to track closely with export growth, suggesting a weak link between trade partners' income growth and the rapid growth in exports of the AM economies.

Considering the growth rate in price competiveness (EPC) for each country, we have graphed the growth in the inverse of our price competitiveness measure, so that an increase in EPC represents lower growth in export prices and hence greater price competitiveness. For most countries there is very little growth and the growth rate is often negative. Overall, there is no clear relationship between growth in price competitiveness and export growth.

On the other hand, there is some evidence that the growth rates in the stock of knowledge (STK) and knowledge competitiveness (COM) may have been influential for exports in the AM economies. STK and COM have both grown rapidly, particularly in China, Singapore and Taiwan. In Japan and Taiwan, the growth of these factors also appears to slow as export growth slows in the 1980's. Nevertheless, the evidence is certainly not clear. In particular, the data for Korea show very little correlation between the growth in STK or COM and export growth. Likewise, in a few instances some of the countries have experienced spells of negative growth rates in knowledge competitiveness when export growth is strong and positive. Thus, knowledge stock and knowledge competitiveness may potentially have been important drivers behind the increases in exports among the AM economies, but the evidence is far from clear from a simple visual inspection. Clearly, a more careful and formal analysis of the data is warranted.

3.5 Baseline regression results

The regression results for Eq. (4) are presented in Table 3. Considering first the OLS estimates in panel A, foreign income and export price competitiveness are significant determinants of export performance as predicted by our model and conventional models of exports. The coefficient of trade weighted income, however, is highly sensitive to the inclusion of innovation stock variables, indicating that the coefficient of trade weighted income is upwardly biased due to the omission of innovation variables in conventional export models. This can be seen by comparing the income elasticity estimates in Table 3 and the first column in Table 6, where innovation variables are excluded from the regression. The income elasticity is 2.7 when the innovation variables are excluded from the regressions (first column in Table 6); however, the income elasticity shrinks to 1.6 when innovations are measured by R&D (first column in Table 3), which is probably the best measure of quality innovations as discussed below. An elasticity of 1.6 is probably much more realistic than one of 2.7 since the export-GDP ratio would otherwise increase to an unrealistically high value as income increases and, in the limit, exceeds its logical threshold.

[Insert Table 3 here]

Finally, the coefficients of innovation stock are statistically significant in all cases, regardless of which measure of innovation stock is included in the regression, reinforcing the importance of including innovative variables in the regressions. The innovation variables are also economically highly significant. The innovation stock has, on average, increased about nine percent annually, which means that it has contributed to an approximately three percent annual increase in exports based on the principal component estimates in the last column in panel A in Table 3.

Turning to the IV estimates, consider first the first-round regressions that are presented in the online appendix, Table A2. The coefficients of the focus variables in the innovation stock regression, i.e., cohort infant mortality and temperature, are mostly statistically highly significant and of the right sign. Cohort infant mortality is also economically highly significant and has been the main factor behind the trend increase in the innovative stock (the simulations are not shown). For the price equations associated with estimates of Eq. (4) the coefficients of union membership and real food prices are all positive and, statistically, highly significant.

Various test statistics for instrument adequacy are reported in panel C in Table 3. The tests do not give evidence against the instruments. The first-stage *R*-squared values and the *F*-test of excluded instruments for both the innovation and export price competitiveness are each favorable to our identification strategy. The *F*-values are well above the rule-of-thumb critical value of 10 except in one case where it is 9.4. Note that the *F*-tests and *R*-squared tests are, for competitiveness, the same in all columns because the dependent variable is the same. The Kleibergen-Paap test rejects the hypothesis of under-identification in almost all cases, suggesting that the excluded instruments are correlated with the endogenous regressors and, therefore, are relevant instruments. In all but one case, the Hansen *J*-test statistics indicate the null hypothesis that the instruments are uncorrelated with the error term cannot be rejected, suggesting that the excluded instruments are valid and are correctly excluded from the structural equation. Finally, the Kleibergen-Paap tests of weak identification suggest that the excluded instruments are correlated with the endogenous regressors, thus rejecting the null hypothesis that the instruments are weak. Overall, these results give strong evidence in favor of the chosen instruments.

Panel B in Table 3 provides the IV estimates based on the fixed-effect estimator. The coefficients of foreign income are almost identical to the OLS estimates, which is not surprising since foreign income is un-instrumented in both regressions. The value of price competitiveness has, however, changed from an average value of -0.85 to an average value of -0.36 in moving from the OLS to the IV regressions. This result is consistent with the analysis of Madsen (1999) showing that the coefficient of price competitiveness is asymptotically biased towards -1 in OLS regressions, as discussed above. If the absolute value of import elasticities are symmetrical to export price elasticities these results imply that the Marshal-Lerner condition that the sum of the absolute values of import and export price elasticities have to exceed one for a depreciation to improve the trade balance, is not satisfied.

The coefficients of the innovation stock variables remain significant and of the expected sign in all the IV regressions, reinforcing the OLS results that innovation is important for export performance. The magnitude of the coefficients has, on average, not changed much from going from the OLS to the IV fixed effect estimator. This implies that innovations are genuinely promoting exports and that the OLS estimates have not been driven by a third factor that has simultaneously promoted exports and innovations such as market reforms and changes in property right institutions. The coefficient of R&D knowledge, which is our preferred measure of innovation stock, is 0.46. This implies that the average 10.3% increase in R&D stock has contributed to a 4.7% annual increase in exports in the AM countries, which is a large contribution to the average 11.1% increase in exports. Trade-weighted income, on the other hand, has contributed 6.7% to export growth. However, it is likely that trade-weighted income in the regressions has captured the contribution of foreign market access along with the improvement of supply conditions, as argued by Redding and Venables (2003), or by other forces as discussed below.

The results of estimating Eq. (5) are presented in Table 4. The tests for instrument adequacy do not, in almost all cases, give evidence against the instruments. The first-stage *R*-squared values and the *F*-test of excluded instruments are both good, the Kleibergen-Paap test of under identification rejects the hypothesis of under-identification in almost all cases and Hansen's *J*-test statistics indicate the null hypothesis that the instruments are uncorrelated with the error term cannot be rejected. Furthermore, cohort infant mortality and temperature, are mostly highly significant and of the right sign for innovative competitiveness (Online Appendix, Table A3). Cohort infant mortality is also economically highly significant and has been the main factor behind the trend increase in innovative competitiveness in the AM economies. For the price equations associated with estimates of Eq. (5) the coefficients of union membership and real food prices are all positive and statistically significant. Simulations of the models show that real food prices and union membership rates have been about equally important in explaining the path of price competitiveness.

[Insert Table 4 here]

The coefficients of trade weighted income are higher than those in Table 3, which is likely to reflect the fact that innovation stock is no longer included in the regression as a scale variable and, therefore, that income has taken over as the principal scale variable. The absolute value of price competitiveness is, again, reduced substantially in going from the OLS to the IV estimates. The point estimate is, on average, 0.29, which is even lower than the average estimate from Table 3, giving further evidence against depreciations as means of improving trade balances.

Finally, the coefficients of innovative competitiveness are all statistically significant and of the expected sign. Importantly, the coefficients of trademarks and product design competitiveness are larger than those of R&D and patent competitiveness; a result that is almost opposite to the results for innovation stock. These results suggest that firms in the AM economies compete more on design than the quality of products, while the opposite holds true for product innovations.

3.6 System approach

The estimators used to produce the results in Tables 3 and 4 have not explicitly dealt with short-run dynamics. The panel vector error-correction model (VECM) and the between-dimension fully-modified OLS (FM-OLS) estimators are used in this sub-section, implying that instruments are not used. The VECM is a system approach that not only allows for short-run dynamics, but also corrects for endogeneity bias by treating all underlying variables as endogenous while the FM-OLS estimator applies semi-parametric correction to the OLS estimator to eliminate the endogeneity bias. The panel unit root and cointegration tests discussed in the online appendix (Section B) suggest that all variables contain unit roots and the models specified in Eqs. (4) and (5) are cointegrated, indicating that using the VECM and the FM-OLS approaches are appropriate supplements to the IV regressions.

[Insert Table 5 here]

The VECM and the FM-OLS results, which are presented in Table 5, are, to a large extent, consistent with the base-line IV results in Tables 3 and 4. However, they differ in three important respects from the base-line results. First, the absolute values of the coefficients of the competitiveness variables are low and even lower than the IV regressions, giving further evidence against devaluations/depreciations as tools for improving trade balances. Second, the coefficients of innovations stock and innovative competitiveness are more significant determinants of export volumes than in the OLS-IV regressions, indicating that their elasticities may be underestimated in Tables 3 and 4. Third, the income elasticities are even lower in the FM-OLS regressions than in the other regressions; thus reinforcing the discussion above that income elasticity appears to be beyond its logical size when innovation stock and innovative competitiveness are excluded from the regressions.

Finally, the error-correction terms are highly significant and of the right sign in the VECM regressions, suggesting that export volume is cointegrated with the regressors. The importance of this result is that the models are adequate and capture the most important driving forces for exports.

4. Further Analyses and Robustness Checks

This sub-section conducts some sensitivity checks on the results. Given that the results, so far, are very robust to how innovation is measured the analysis henceforth considers only the first principal component measures to conserve space and all the results are based on the fixed-effect IV estimator.

[Insert Table 6 here]

4.1 Conventional export model

Consider first, estimates of a conventional export equation in the first column in Table 6. The coefficient of foreign income is 2.7, which, as discussed above, is unrealistically high seen from the perspective that it cannot possibly represent a steady state solution since the export-income ratio would exceed its logical limit at some stage as productivity advances. As shown by Krugman (1989), high income elasticities are found for countries that are growing rapidly while they are low for slowly growing countries. Since technological progress is simply given by an exogenous time trend in standard neoclassical growth models we first consider a version of the model that omits the innovation variables.

4.2 Competitiveness omitted

Export price competitiveness is omitted from the regressions in column (2) since the model in Section 2 implies that export price competitiveness is not an essential determinant for export performance. The size and the significance of the coefficients of income, innovation stock and innovative competitiveness remain influential for exports, suggesting that the results are not sensitive to the exclusion of export price competitiveness from the regression model.

4.3 Contracting institutions

An emerging literature stresses the quality of institutions as important for export performance because transaction costs are inversely related to the quality of institutions. Levchenko (2007)) and Costinot (2009) argue that imperfect contract enforcement increases transaction costs and that reduced transaction costs increase the economic viability of the production of complex products; thus boosting exports. The more complex is the production of a good the longer it takes to learn how to perform the required tasks and the larger are the gains from division of labor (Costinot, 2009). If the worker's contract is enforced, she performs her task in accordance with the terms of her contract; otherwise she does not perform at all. Related to this, contract enforcement also matters for exports because it allows agents to overcome frictions that arise when two parties with competing interests enter a production relationship (Levchenko, 2007). Thus, as the contractual arrangements improve the complex sector gains comparative advantage in exports vis-à-vis its competitors (Levchenko, 2007).

An index of the quality of contracting institutions is included in the regressions to examine the transaction cost hypothesis. Contracting institutions are measured by an index of intellectual property rights (IPR). The index covers five dimensions: (1) patentability of various kinds of inventions; (2) membership in international patent arrangements; (3) provisions for loss protection; (4) enforcement mechanisms; and (5) duration of the patent term. Each dimension is assigned a value ranging from zero to one.

The unweighted sum of these five values provides an indication of the overall level of IPR protection, with higher values reflecting greater levels of protection. We use IPR as a measure of the quality of contracting institutions because time-series data on contracting institutions are not available and because there is likely to be a high positive correlation between the quality of contracting institutions and enforcement of property rights.

The results of adding IPR to the baseline regressions are show in columns (4) and (5) in Table 6. The coefficients of IPRs are insignificant at conventional significance levels in both cases and the results from the baseline regressions remain intact. The insignificance of coefficients of IPRs may be due to measurement errors since IPR does not measure contracting institutions directly.

4.4 Democracy

Democracy may have positive effects on trade because democratic states are more likely to cooperate on trade policies. Mansfield et al. (2002) show, theoretically as well as empirically, that international cooperation in trade is influenced by the control that voters exert over political leaders. A key in their model is that trade agreements can enhance the utility of both heads of state and voters; thus prompting the leaders to engage in international cooperation on commercial issues and trade agreements to maintain their position in office.

Polity IV's index of democracy (*polity 2*) is included as an additional regressor to the baseline model and the results are shown in columns (3) and (4) in Table 6. *Polity 2* is measured as the difference between the degree of democracy and autocracy, where a higher value reflects the presence of a more democratic regime. The coefficients of democracy are insignificant and the baseline results remain intact.

4.5 Trade costs

Bilateral trade arrangements and Costs of Insurance and Freight (CIF) are included in the regressions as measures of trade costs. Bilateral trade agreements are measured as the number of available trade agreements between an AM economy and other economies in the region in any particular year. A bilateral trade agreement takes the value of one for the year in which the agreement has been sealed and remains one as long as the agreement is in force and zero otherwise. The number of bilateral trade agreements between country *i* (home country) and country *j* (any export partner) is calculated. A free trade agreement is likely to enhance exports because of a public commitment by leaders to a less protectionist policy than otherwise. Adding bilateral trade agreements to our baseline regressions (columns (3)-(5) in Table 6) does not alter the baseline regression results. The coefficients of trade agreements are positive and statistically significant at the 10% level in half of the cases; otherwise they are insignificant. Economically, trade agreements are not that influential for trade; 50 trade agreements are required to lift exports by one percent.

Insurance and freight costs are included in the regression in the last column in Table 6. Trade costs are proxied by the CIF-FOB ratio, where FOB is Free on Board value, which is the value at the exporter's border while the importer declares the CIF mirror value. The baseline regression results remain intact while the coefficient of the CIF-FOB ratio is insignificant. Its significance may be due to small identifying variations in the CIF-FOB ratio and the fact that the CIF-FOB ratio has only been a small fraction of the total costs of the final goods. Furthermore, exporters may absorb changes in CIF-FOB trade costs in their mark-ups, at least in the short run.

4.6 Restricted samples

Although the AM economies share a marked success in productivity and export growth in the *post*-WWII period there are significant differences between the countries in the group and this difference may influence the response of exports to innovations. There is evidence of very high levels of incremental innovation in China and India and the emergence of Asian value chains suggests that the relationship between innovation and trade may have shifted in important ways over time due to falling direct and indirect trade costs. The recent literature on Asian trade networks shows that in India and China the process of export led growth has differed in important ways from the earlier AM economies. First it has been widely observed that China's export processing trade has very low value added so that China's comparative advantage is in labor intensive assembly rather than the final goods it actually exports, with the classic example being the iPad (Linden et al., 2009). Second, Puga and Trefler (2010) argue that there has been a rapid increase in incremental innovation – that is innovation leading to new intermediate goods that are traded - in a small number of low wage countries including, in particular, India and China.[6] Similar evidence is given by Hanson (2012) and Baldwin and Lopez-Gonzalez (2013). Thus Asian value chains may have facilitated specialization in intermediate stages of production which has, in turn, facilitated the production of new intermediate goods.

The figures above show that China's innovation boom does not coincide with its export boom, which started earlier and that the time when the countries opened up to international trade differ between India and China and the other AM economies. Korea and Japan, for example, opened up to trade much earlier than India and China. Consequently, confounding factors may have plagued the regression results above and it would be valuable to decompose the AM economies into country groups. To that end Table 7 reports the results for the following three country groups: 1) China and India; 2) Singapore, Taiwan, Japan and Korea; and 3) Korea and Japan.

[Insert Table 7 here]

The regression results differ in certain respects from the baseline regressions; however, they are more favorable to the hypothesis in this paper than the baseline regression results. First, the income elasticities are, on average, significantly lower in Table 7 than in the baseline regressions; thus, giving further support to the Krugman thesis that income elasticities in many empirical studies tend to be biased upwards due to the omission of innovation variables and the pooling of data across countries. Second, the price elasticities are, on average, slightly more negative than the baseline regressions but still not sufficiently negative to ensure that the Marshal-Lerner condition is met with confidence. Third, the coefficients of the innovation stock and innovative competitiveness are substantially higher than the coefficient of 0.30 in the baseline regressions in Table 3 and 4, except for the China and India group where they are similar to the baseline regressions.

In summary, the coefficients of the innovation stock and competitiveness variables tend to be larger for the group consisting of Singapore, Taiwan, Japan and

Korea, suggesting that innovation was more important for these countries than it, thus far, has been for China and India. On the face of it this result appears to be evidence against the Puga and Trefler (2010) hypothesis that there has been a rapid increase in incremental innovation in China and India. However, to consider this more carefully we need to consider the type of innovation being undertaken. Hence, we now turn to consider whether we can identify separate impacts from different types of innovations.

4.7 Product variety versus product quality

Thus far we have included the innovation variables separately in the regressions; however, these variables may complement each other. As noted above, patents and R&D are more likely to result from improved product quality while new trademarks and product designs are more likely to reflect changes in product variety. To investigate this issue various combinations of the innovation variables are considered in this section.

The regressions in Table 8 include different combinations of product variety (trademarks and product designs) and product quality (R&D and patents) measures. The results are encouraging in that they show that the proxies for product variety and product quality mostly complement each other and, in most cases, are significant. Thus, for example, in Columns (1), (2) and (6) in Table 8 it can be seen that both the R&D and the product variety variables are significant. The main difference between these results and those of the baseline regressions is that the coefficients of innovation stock and innovative competitiveness are less significant in Table 8; predominantly reflecting the fact that the innovation variables are highly correlated.

[Insert Table 8 here]

Next consider the Puga and Trefler (2010) hypothesis that the export growth in China and India has been driven more by innovations in production streams, rather than the traditional product cycle factor of relocation of standardized technologies. Specifically they argue that a central feature behind the recent success of India and China has been the ability of these countries to deliver incremental innovation to foreign companies operating complex supply chains.

To further investigate the Puga-Trefler hypothesis regressions in Table 9 consider combinations of our alternative measures of innovation for China and India. The results show that end-product variety (designs and trademarks) are not significant determinants of exports at any conventional significance levels. However, as can be seen in columns (3), (4), (7), and (8) our measures of patent stock and patent competitiveness are significant for India and China. This suggests that there is indeed significant innovation in these two economies, which, as argued by Puga and Trefler (2010), is likely to be incremental process innovation. Thus the results give some evidence in favor of the Puga and Trefler (2010) hypothesis.

[Insert Table 9 here]

5. Concluding remarks

The Asian miracle economies have experienced a marked increase in exports, and yet only a very few attempts, like Redding and Venables (2003), Jongwanich (2010), and Puga and Trefler (2010), have been made to explain the export success of these countries. This is a mystery in the light of the emphasis on openness as a key driver of growth in the development literature and the fact that export growth and trade openness have often been stressed as factors that have been influential for the success of the AM economies (see, for discussion, Lucas, 1993; Easterly, 1994; Rodrik, 1996, 1997; and Radelet et al., 2001). This paper has argued that the spectacular productivity and export growth rates of the AM countries have in common that they are both predominantly driven by innovations. Based on a simple product variety endogenous growth model it is shown that export growth is an outcome of new product variety, which in turn is an outcome of R&D in the intermediate goods producing sector. An R&D-induced increase in product variety affects exports directly as well as indirectly, through improved innovation stock and innovative competitiveness.

The innovation hypothesis was tested for the AM economies in the period 1953-2010 and external instruments were used to ensure that the results were not driven by unobserved heterogeneity. Unionization and real food prices were used as instruments for prices to construct price competitiveness while cohort infant mortality and temperature were used as instruments for innovation stock and innovative competitiveness. The regression results gave strong support to the innovation-driven export growth hypothesis. Innovation stock and innovative competitiveness were both significant determinants of exports along with trade weighted income, whereas price competitiveness was not a quantitatively important determinant of exports.

The IV regressions gave stronger support for the innovation hypothesis than the OLS estimates and showed that the price elasticities were significantly lower in the IV than in the OLS estimates. This not only highlights the importance of using external instruments but also reinforces the argument that policies that speed up innovations/imitations are much more effective in rectifying current account deficits than devaluations/depreciations. Finally, we found innovation stock and innovative competitiveness to have been significantly less influential for export growth for China and India than the other AM economies and that these countries' export booms have been predominantly based on incremental innovation/imitation (process innovation) and not fundamental innovation (product innovation) as predicted by the model of Puga and Trefler (2010).

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Table 1: Average annual percentage growth rate of all variables (1953-2010)

Variable	China	India	Japan	Korea	Singapore	Taiwan	AM
Export volume (*EX*)	11.92	6.48	9.16	18.52	10.17	10.45	11.12
Trade weighted income (*TWI*)	3.51	3.43	4.41	4.68	3.77	5.44	4.21
Export price competitiveness (P^{ex})	-1.98	0.33	2.01	-4.85	0.98	-1.26	-0.80
R&D stock (STK^{RD})	10.20	10.42	7.74	8.87	12.80	11.94	10.33
Patent stock (STK^{PS})	16.68	4.21	6.21	9.26	10.19	10.71	9.54
Trade mark stock (STK^{TM})	16.50	5.49	3.25	11.56	4.46	8.51	8.29
Product design stock (STK^{PD})	29.93	0.04	3.63	8.81	1.74	-0.08	7.35
R&D stock competitiveness (COM^{RD})	6.83	7.15	-2.04	4.51	9.05	7.09	5.43
Patent stock competitiveness (COM^{PS})	15.24	1.87	1.33	4.53	9.96	4.66	6.26
Trade mark stock competitiveness (COM^{TM})	3.67	1.17	-2.21	5.90	-0.09	3.15	1.93
Product design stock competitiveness (COM^{PD})	9.09	-2.28	0.14	4.04	-0.88	-4.54	0.93

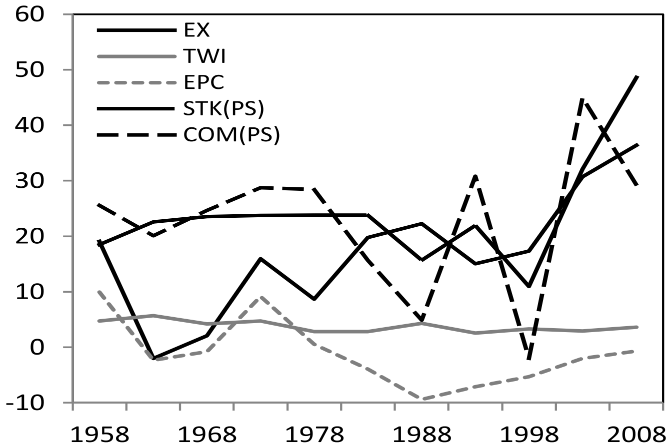
Notes. the growth rates are geometric averages. The AM figures reflect the unweighted averages of the six AM economies.

Table 2: Real export volume

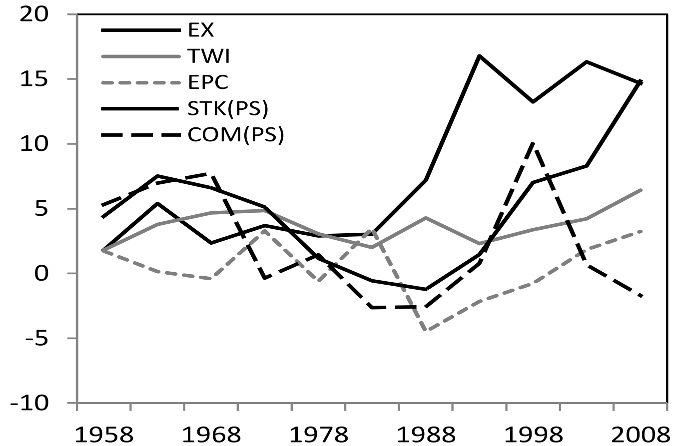
	World	Industrial Countries	Developing Countries	Developing Countries: Africa	Developing Countries: Asia	Developing Countries: Europe	Developing Countries: Middle East	Developing Countries: Western Hemisphere
1950	3.682	2.486	1.447	0.330	0.162	0.010	0.778	0.360
1960	6.404	4.873	2.248	0.557	0.232	0.023	1.470	0.490
1970	13.429	11.082	3.815	0.898	0.314	0.053	3.842	0.674
1980	24.953	20.597	5.190	1.271	0.871	0.166	2.562	1.321
1990	36.353	31.048	7.900	1.028	2.405	0.425	2.702	1.540
2000	77.653	57.040	21.706	1.303	7.207	3.956	5.050	4.552
2010	127.666	80.564	42.051	3.082	21.007	9.092	6.461	6.073
Annual average growth rate	6.1%	6.0%	5.8%	3.8%	8.4%	12.0%	3.6%	4.8%

Figure 1: Growth rates of key variables (1953-2010)

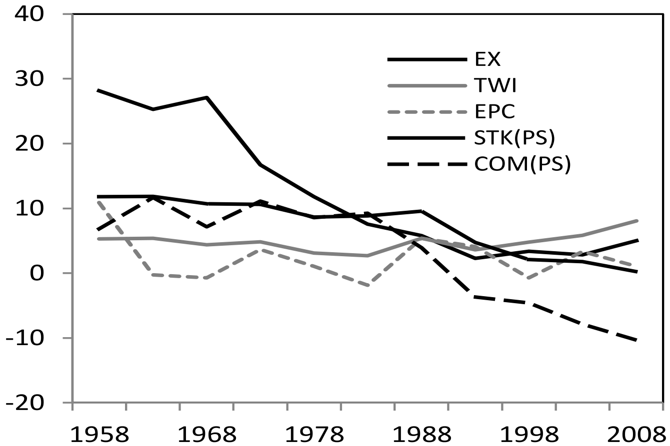
(a) China



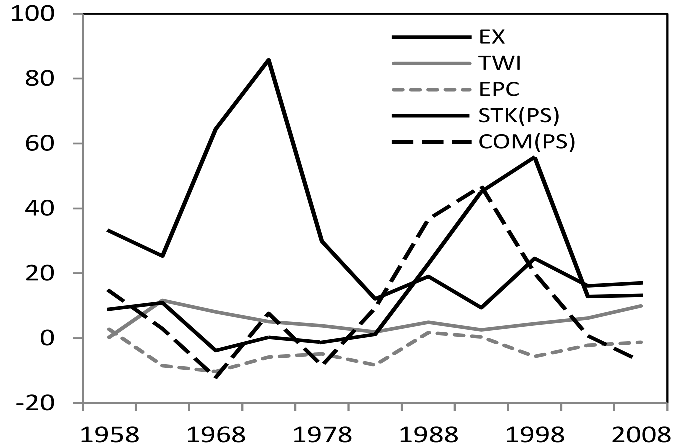
(b) India

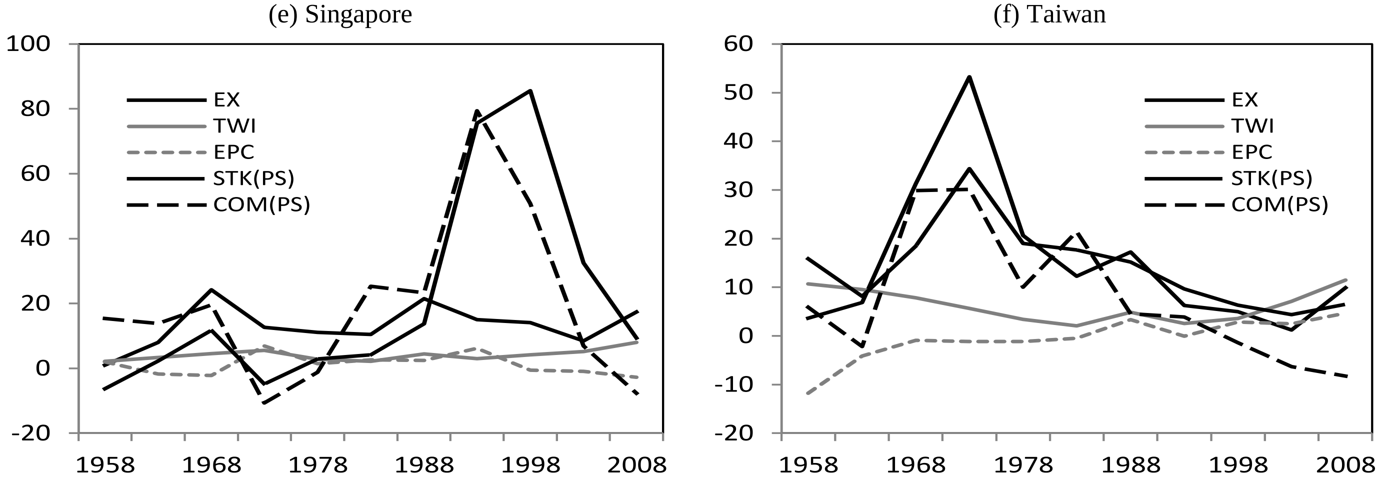


(c) Japan



(d) Korea





Notes: the knowledge stock variables (STK and COM) are based on the stock of patents. All variables are measured in annualized growth rates over 5-year periods. See the online appendix (section E) for the sources.

Table 3: Innovation stock and export performance

	(1)	(2)	(3)	(4)	(5)
Dep. Var. = Total export volume (*EX*)			**Panel A: Pooled OLS estimates**		
Trade weighted income (*TWI*)	1.598***	2.080***	2.016***	2.488***	2.009***
	(0.131)	(0.094)	(0.121)	(0.064)	(0.133)
Export price competitiveness (P^{ex})	-1.078***	-0.897***	-0.653***	-0.850***	-0.748***
	(0.061)	(0.068)	(0.088)	(0.087)	(0.082)
R&D stock (STK^{RD})	0.386***				
	(0.057)				
Patent stock (STK^{PS})		0.200***			
		(0.033)			
Trade mark stock (STK^{TM})			0.289***		
			(0.064)		
Product design stock (STK^{PD})				0.044*	
				(0.026)	
1st principal component of innovation stock (STK^{PC})					0.327***
					(0.081)
R-squared	0.939	0.938	0.938	0.931	0.938
Dep. Var. = Total export volume (*EX*)			**Panel B: Panel IV-FE estimates**		
Trade weighted income (*TWI*)	1.582***	2.182***	2.224***	2.519***	2.122***
	(0.510)	(0.287)	(0.203)	(0.097)	(0.230)
Export price competitiveness (P^{ex})	-0.517***	-0.555***	-0.201	-0.240	-0.290**
	(0.146)	(0.134)	(0.157)	(0.163)	(0.143)
R&D stock (STK^{RD})	0.455**				
	(0.209)				
Patent stock (STK^{PS})		0.194*			
		(0.109)			
Trade mark stock (STK^{TM})			0.244**		
			(0.098)		
Product design stock (STK^{PD})				0.123**	
				(0.053)	
1st principal component of innovation stock (STK^{PC})					0.330***
					(0.127)
R-squared	0.917	0.931	0.922	0.915	0.925
No. of observations	348	348	348	348	348

No. of countries	6	6	6	6	6
			Panel C: Diagnostic tests for panel IV-FE estimates		
1st-stage *R*-squared (*STK* equation)	0.910	0.788	0.843	0.448	0.844
F-test of excluded IV (*STK* equation)	9.400	14.820	29.840	18.030	20.280
1st-stage *R*-squared (*EPC* equation)	0.428	0.428	0.428	0.428	0.428
F-test of excluded IV (P^{ex} equation)	29.230	29.230	29.230	29.230	29.230
Kleibergen-Paap test of under identification	30.089 [0.000]	22.918 [0.000]	52.448 [0.000]	43.276 [0.000]	55.261 [0.000]
Hansen *J*-test (over identification test of all instruments)	3.889 [0.143]	7.962 [0.019]	4.144 [0.126]	3.782 [0.151]	3.761 [0.153]
Kleibergen-Paap test of weak identification	8.748 {7.560}	7.332 {7.560}	29.338 {7.560}	20.500 {7.560}	22.074 {7.560}

Notes: The Kleibergen-Paap under-identification test is the robust version of the Anderson canonical correlations test. Its null hypothesis is that the equation is identified, meaning that the excluded instruments are irrelevant. The Hansen *J*-test is a test of over-identifying restrictions with the null hypothesis that the instruments are valid. The Kleibergen-Paap test of weak identification is the robust version of the Cragg-Donald test and tests whether the excluded instruments are correlated with the endogenous regressors. The null hypothesis is that the instruments are weak. Robust standard errors are reported in the round parentheses. Figures in [ ] report *p*-values whereas those in { } show the Stock-Yogo critical value for the Kleibergen-Paap test of weak identification using the 10% maximal IV relative bias as the decision rule. Country-specific fixed effects are included in the estimations. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 4: Innovative competitiveness and export performance

	(1)	(2)	(3)	(4)	(5)
Dep. Var. = Total export volume (*EX*)			**Panel A: Pooled OLS estimates**		
Trade weighted income (*TWI*)	2.279***	2.156***	2.243***	2.543***	2.028***
	(0.081)	(0.060)	(0.047)	(0.045)	(0.049)
Export price competitiveness (P^{ex})	-0.948***	-0.888***	-0.254***	-0.444***	-0.438***
	(0.064)	(0.064)	(0.075)	(0.087)	(0.077)
R&D stock competitiveness (COM^{RD})	0.204***				
	(0.048)				
Patent stock competitiveness (COM^{PS})		0.239***			
		(0.028)			
Trade mark stock competitiveness (COM^{TM})			0.671***		
			(0.036)		
Product design stock competitiveness (COM^{PD})				0.290***	
				(0.031)	
1st principal component of innovative competitiveness (COM^{PC})					0.419***
					(0.024)
R-squared	0.936	0.946	0.956	0.946	0.959
Dep. Var. = Total export volume (*EX*)			**Panel B: Panel IV-FE estimates**		
Trade weighted income (*TWI*)	2.234***	2.165***	2.446***	2.621***	2.263***
	(0.262)	(0.134)	(0.106)	(0.059)	(0.116)
Export price competitiveness (P^{ex})	-0.339*	-0.598***	-0.105	-0.198	-0.215
	(0.199)	(0.135)	(0.182)	(0.144)	(0.152)
R&D stock competitiveness (COM^{RD})	0.366*				
	(0.208)				
Patent stock competitiveness (COM^{PS})		0.279***			
		(0.070)			
Trade mark stock competitiveness (COM^{TM})			0.435***		
			(0.150)		
Product design stock competitiveness (COM^{PD})				0.255***	
				(0.071)	
1st principal component of innovative competitiveness (COM^{PC})					0.302***
					(0.073)
R-squared	0.908	0.940	0.943	0.940	0.949
No. of observations	348	348	348	348	348

No. of countries	6	6	6	6	6
	Panel C: Diagnostic tests for panel IV-FE estimates				
1st-stage *R*-squared (*COM* equation)	0.909	0.779	0.835	0.397	0.835
F-test of excluded IV (*COM* equation)	8.230	22.240	15.220	15.690	18.920
1st-stage *R*-squared (P^{ex} equation)	0.385	0.385	0.385	0.385	0.385
F-test of excluded IV (*EPC* equation)	25.830	25.830	25.830	25.830	25.830
Kleibergen-Paap test of under identification	22.948 [0.000]	26.818 [0.000]	49.585 [0.000]	43.516 [0.000]	38.821 [0.000]
Hansen J-test (over identification test of all instruments)	9.338 [0.010]	1.131 [0.568]	4.671 [0.097]	5.825 [0.054]	1.266 [0.531]
Kleibergen-Paap test of weak identification	6.284 {7.560}	10.697 {7.560}	16.930 {7.560}	16.761 {7.560}	19.639 {7.560}

Notes: The Kleibergen-Paap under-identification test is the robust version of the Anderson canonical correlations test. Its null hypothesis is that the equation is identified, meaning that the excluded instruments are irrelevant. The Hansen *J*-test is a test of over-identifying restrictions with the null hypothesis that the instruments are valid. The Kleibergen-Paap test of weak identification tests whether the excluded instruments are correlated with the endogenous regressors. The null hypothesis is that the instruments are weak. Robust standard errors are reported in the round parentheses. Figures in [ ] report the p-values whereas those in { } report the Stock-Yogo critical value for the Kleibergen-Paap test of weak identification using the 10% maximal IV relative bias as the decision rule. Country-specific fixed effects are included in the estimations. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 5: Panel vector error-correction model (VECM) and fully-modified OLS (FM-OLS) estimates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	VECM	VECM	VECM	VECM	VECM	FM-OLS	FM-OLS	FM-OLS	FM-OLS	FM-OLS
Dep. Var. = Total export volume (*EX*)	**Panel A: Export performance and innovation**									
Trade weighted income (*TWI*)	1.97*** (0.22)	2.02*** (0.16)	1.77*** (0.20)	2.10*** (0.18)	1.94*** (0.17)	1.46*** (0.18)	0.93*** (0.11)	0.56*** (0.13)	1.85*** (0.06)	0.54*** (0.08)
Export price competitiveness (P^{ex})	-0.83*** (0.20)	-0.71*** (0.17)	-0.49** (0.20)	0.08 (0.24)	-0.63*** (0.18)	-0.39*** (0.11)	-0.50*** (0.08)	-0.31*** (0.09)	-0.12 (0.10)	-0.56*** (0.07)
R&D stock (STK^{RD})	0.16*** (0.06)					0.49*** (0.06)				
Patent stock (STK^{PS})		0.11*** (0.03)					0.57*** (0.04)			
Trade mark stock (STK^{TM})			0.34*** (0.08)					1.18*** (0.07)		
Product design stock (STK^{PD})				0.30*** (0.06)					1.11*** (0.07)	
1st principal component of innovation stock (STK^{PC})					0.29*** (0.064)					1.48*** (0.04)
Error-correction term	-0.06*** (0.01)	-0.06*** (0.01)	-0.06*** (0.01)	-0.05*** (0.01)	-0.06*** (0.01)	-	-	-	-	-
Dep. Var. = Total export volume (*EX*)	**Panel B: Export performance and innovative competitiveness**									
Trade weighted income (*TWI*)	1.73*** (0.21)	1.89*** (0.15)	2.16*** (0.18)	2.47*** (0.19)	1.95*** (0.14)	2.53*** (16.11)	1.66*** (31.92)	2.11*** (36.91)	2.58*** (47.52)	1.82*** (36.40)
Export price competitiveness (P^{ex})	-0.85*** (0.19)	-0.69*** (0.15)	-0.33 (0.27)	0.47 (0.32)	-0.19 (0.17)	-0.38*** (0.12)	-0.21*** (0.07)	0.01 (0.20)	0.14 (0.1)	-0.16** (0.07)
R&D stock competitiveness (COM^{RD})	0.63*** (0.12)					0.18** (0.09)				
Patent stock competitiveness (COM^{PS})		0.37*** (0.05)					0.52*** (0.02)			

Trade mark stock competitiveness (COM^{TM})			0.340** (0.16)					0.97*** (0.06)		
Product design stock competitiveness (COM^{PD})				0.33*** (0.10)					0.66*** (0.04)	
1st principal component of innovative competitiveness (COM^{PC})					0.43*** (0.06)					0.65*** (0.02)
Error-correction term	-0.06*** (0.009)	-0.07*** (0.010)	-0.06*** (0.009)	-0.04*** (0.007)	-0.08*** (0.010)	-	-	-	-	-
No. of observations	348	348	348	348	348	348	348	348	348	348

Notes: Intercepts but no time trends are included in the regressions. The optimal lag length is chosen based on SBC. Total export volume is normalized as the dependent variable. Country-specific fixed effects are included only in the FM-OLS estimations. Figures in the round parentheses are standard errors. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 6: Robustness checks

	(1)	(2)	(3)	(4)	(5)	(6)
	Exclude innovation variables	Exclude export price	Add trade agreements & IPR	Add trade agreements & Polity 2	Add trade agreements, IPR & Polity 2	Add CIF/FOB ratio
Dep. Var. = Total export volume (*EX*)	**Panel A: Export performance and innovation**					
Trade weighted income (*TWI*)	2.68***	1.81***	1.86***	1.99***	1.85***	2.14***
	(0.07)	(0.33)	(0.20)	(0.21)	(0.19)	(0.23)
Export price comp. (P^{ex})	-0.39**		-0.33**	-0.34**	-0.35**	-0.29**
	(0.18)		(0.14)	(0.14)	(0.14)	(0.14)
1st PC of innovation stock (STK^{PC})		0.55***	0.41***	0.38***	0.41***	0.31***
		(0.20)	(0.12)	(0.12)	(0.12)	(0.12)
Regional trade agreements			0.02*	0.02**	0.02*	
			(0.01)	(0.01)	(0.01)	
IPR index			0.07		-0.00	
			(0.05)		(0.01)	
Polity2				0.00	0.07	
				(0.01)	(0.05)	
CIF/FOB ratio						-0.37
						(1.17)
R-squared	0.91	0.91	0.93	0.93	0.93	0.93
Dep. Var. = Total export volume (*EX*)	**Panel B: Export performance and innovative competitiveness**					
Trade weighted income (*TWI*)	2.68***	2.13***	2.18***	2.10***	2.11***	2.25***
	(0.07)	(0.10)	(0.08)	(0.09)	(0.10)	(0.13)
Export price comp. (P^{ex})	-0.39**		-0.23	-0.25	-0.23	-0.23
	(0.18)		(0.15)	(0.15)	(0.15)	(0.15)
1st PC of innovative comp. (COM^{PC})		0.43***	0.34***	0.35***	0.34***	0.29***
		(0.08)	(0.06)	(0.05)	(0.06)	(0.07)
Regional trade agreements			0.01	0.01	0.01	
			(0.01)	(0.01)	(0.01)	
IPR index				-0.00	0.06	
				(0.01)	(0.04)	

Polity2			0.00	0.06		
			(0.01)	(0.04)		
CIF/FOB ratio						-0.85
						(1.09)
R-squared	0.91	0.95	0.95	0.95	0.95	0.95
No. of obs.	348	348	348	348	348	348

Notes: An intercept is included in all estimations but not reported. Figures in the parentheses are robust standard errors. Country-specific fixed effects are included in the estimations. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively. IPR = intellectual property rights.

Table 7: Restricted samples

Dep. Var. = Total export volume (*EX*)	(1) China & India	(2) Asia 4 (excl. China & India)	(3) Japan & Korea	(4) China & India	(5) Asia 4 (excl. China & India)	(6) Japan & Korea
Trade weighted income (*TWI*)	0.858***	0.569	1.410**	1.748***	1.620***	2.361***
	(0.150)	(0.534)	(0.568)	(0.140)	(0.422)	(0.088)
Export price competitiveness (P^{ex})	-0.716***	-0.477***	-0.555**	-0.724*	-0.333*	-0.608***
	(0.191)	(0.096)	(0.242)	(0.366)	(0.172)	(0.128)
1st principal component of innovation stock (STK^{PC})	0.361***	1.581***	1.287***			
	(0.093)	(0.319)	(0.475)			
1st principal component of innovative competitiveness (COM^{PC})				0.230*	0.848***	0.498***
				(0.132)	(0.227)	(0.076)
R-squared	0.979	0.978	0.991	0.970	0.967	0.988
No. of observations	116	232	116	116	232	116
No. of countries	2	4	2	2	4	2

Notes: An intercept is included in all estimations but not reported. Figures in the parentheses are robust standard errors. Country-specific fixed effects are included in the estimations. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 8: Product variety versus product quality

Dep. Var. = Total export volume (*EX*)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Trade weighted income (*TWI*)	1.439***	1.556***	2.533***	3.786***	2.185***	2.209***	2.019***	2.231***
	(0.491)	(0.484)	(0.393)	(1.031)	(0.246)	(0.190)	(0.164)	(0.217)
Export price competitiveness	-0.285	-0.308	0.214	0.579	-0.044	-0.049	-0.993**	-0.513**
(P^{ex})	(0.192)	(0.192)	(0.457)	(0.720)	(0.214)	(0.193)	(0.408)	(0.201)
R&D stock (STK^{RD})	0.359*	0.411**						
	(0.215)	(0.206)						
Patent stock (STK^{PS})			-0.306	-0.644				
			(0.339)	(0.551)				
Trade mark stock (STK^{TM})	0.207*		0.494					
	(0.111)		(0.303)					
Product design stock (STK^{PD})		0.114**		0.406				
		(0.058)		(0.263)				
R&D stock competitiveness					0.249	0.362**		
(COM^{RD})					(0.187)	(0.157)		
Patent stock competitiveness							0.461***	0.236*
(COM^{PS})							(0.174)	(0.128)
Trade mark stock					0.387**		-0.366	
competitiveness (COM^{TM})					(0.154)		(0.367)	
Product design stock						0.254***		0.060
competitiveness (COM^{PD})						(0.069)		(0.125)
R-squared	0.922	0.920	0.886	0.789	0.935	0.940	0.916	0.943
No. of observations	348	348	348	348	348	348	348	348

Notes: An intercept is included in all estimations but not reported. Figures in the parentheses are robust standard errors. Country-specific fixed effects are included in the estimations. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 9: Product variety versus product quality for China and India only

Dep. Var. = Total export volume (*EX*)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Trade weighted income (*TWI*)	-1.549	-0.875	1.452***	0.550	2.193***	2.263***	-0.122	-0.191
	(2.237)	(1.958)	(0.336)	(0.405)	(0.742)	(0.777)	(0.415)	(0.469)
Export price competitiveness	-1.791**	-1.786**	-0.921***	-0.787***	-0.811	-0.548	-0.232	-0.286
(P^{ex})	(0.761)	(0.754)	(0.272)	(0.248)	(0.974)	(2.923)	(0.318)	(0.942)
R&D stock (STK^{RD})	0.849	0.777						
	(0.694)	(0.667)						
Patent stock (STK^{PS})			0.529**	0.596**				
			(0.247)	(0.258)				
Trade mark stock (STK^{TM})	0.261		-0.456					
	(0.197)		(0.313)					
Product design stock (STK^{PD})		0.079		-0.168				
		(0.056)		(0.101)				
R&D stock competitiveness					-0.524	-0.470		
(COM^{RD})					(0.313)	(0.344)		
Patent stock competitiveness							0.323***	0.330***
(COM^{PS})							(0.070)	(0.081)
Trade mark stock					-0.136		0.027	
competitiveness (COM^{TM})					(0.735)		(0.202)	
Product design stock						0.022		-0.006
competitiveness (COM^{PD})						(0.690)		(0.225)
R-squared	0.938	0.941	0.977	0.984	0.971	0.975	0.995	0.994
No. of observations	116	116	116	116	116	116	116	116

Notes: An intercept is included in all estimations but is not reported. Figures in the parentheses are robust standard errors. Country-specific fixed effects are included in the estimations. *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Endnotes:

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[1] We focus on trade in intermediate goods in the interest of parsimony but similar models can be used to motivate final goods trade. In particular, see the discussion of the substitutability of intermediate goods and final goods concepts in the growth models described in Grossman and Helpman (1992, pp. 45-48).

[2] This specification assumes that all goods sold in each country *i*, sourced from country *j*, have the same price. This will be true in equilibrium and follows from the assumption that, within each source country, firms face the same marginal cost of production for intermediate goods.

[3] It can be shown that this term is related to the share of country *j*'s exports in country *i*'s total imports Specifically $(p_j / P_i)^{-\sigma} = x_{ij} / z_i$ and

$N_j (x_{ij} / z_i)^{(\sigma-1)/\sigma} = x_j^{\alpha} N_j / (\sum_j x_j^{\alpha} N_j) = p_j x_{ij} N_j / \alpha Y_i$, which is the share of imports from country j in country i's total spending on intermediate inputs.

[4] The number of varieties, N_j, and the cost of intermediate goods, □$_j$, may be related in general equilibrium, but need not be, as shown for example in Rodrik (1996). Here, we follow the gravity trade literature (e.g., Baier and Bergstrand (2001)) by treating N_j as exogenous for the purpose of our empirical model.

[5] We initially considered a multilateral competitiveness index which is based on the market shares of competitors in the export markets, including the market share of the domestic producer (see, for derivation, Madsen, 1998a). The advantage of such a multilateral index is that it also allows for competition from exporters from other export markets selling in country i's export market. However, it was not possible to construct such an index here because the sales revenue of domestic manufacturing producers is not available for most of the countries in the sample.

[6] For example they show that of all the medium technology new goods imported to the United States, from 2000-2002, 48% of these were sourced from China and 10% from India, making these two countries more important as a source of new goods than Japan.