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Trade Barriers, Openness, and Economic Growth

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Using a long data set on openness and productivity, this article tests the influence of openness on total factor productivity (TFP) growth and per capita growth since 1870 for 16 industrialized countries. It is shown, in simple regressions, that growth is, by and large, independent of openness. However, once the interaction between openness and foreign knowledge is allowed for, productivity is positively affected by openness.

JEL Classification: F13, F14, F32

1. Introduction

A recurring theme in international economics is the relationship between openness and economic growth. Based on postwar data that typically span the period from 1970 to 1990, there has, until recently, been a consensus of a negative relationship between trade barriers and growth and a positive relationship between growth and import penetration. However, these findings have been challenged by Harrison and Hanson (1999), Rodrik (1999), Yanikkaya (2003), and particularly, Rodríguez and Rodrik (2000).[1] Rodríguez and Rodrik (2000) seriously question the empirical method underlying the regression analysis in the most important studies that find a positive relationship between openness and growth. Rodríguez and Rodrik (2000) demonstrate that the positive correlation between growth and openness found by Dollar (1992), Ben-David (1993), Sachs and Warner (1995), and Edwards (1998) is not robust to various measures of openness and important control variables.

Similarly, studies using pre–World War II data consistently fail to uncover a robust positive relationship between openness and growth (see Bairoch 1972; Capie 1994; Foreman-Peck 1995; O'Rourke 2000; Clements and Williamson 2001; Irwin 2002; Irwin and Terviö 2002; Vamvakidis 2002). The empirical study of Vamvakidis (2002) is one of the few studies that consider the relationship between openness and growth over a long historical period. Using cross-section data over the periods 1870–1910, 1920–1940, 1950–1970, and 1970–1990, Vamvakidis (2002) finds either a negative or no relationship between growth and openness before 1970 and a positive relationship thereafter.

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[1] Often-cited studies finding a negative relationship between trade barriers and economic growth include Dollar (1992), Sachs and Warner (1995), Harrison (1996), Edwards (1998), and Frankel and Romer (1999).

A problem associated with most empirical studies is that cross-sectional data, as opposed to panel data, are used. This prevents them from controlling for fixed effects. More importantly, very little attention has been given to growth versus level effects of openness and, particularly, to the channel through which openness influences growth. Endogenous growth theories have highlighted trade as the principal channel through which knowledge is transmitted internationally (Grossman and Helpman 1991). The early endogenous growth models have been developed within the first generation endogenous growth framework, in which the level of research and development (R&D) activity and growth vary proportionally.

Since the seminal paper of Jones (1995), however, it has been widely believed that first generation growth models are not consistent with the empirical evidence. In response to Jones's critique, endogenous growth theories have evolved into two distinct second generation growth models, namely, semi-endogenous and Schumpeterian growth models. Policies that seek to promote productivity have only temporary growth effects in the semi-endogenous growth models of Jones (1995) and Kortum (1997). In the Schumpeterian models of Aghion and Howitt (1998) and Howitt (1999), R&D can have permanent growth effects so long as R&D is increased along with income in the economy to counteract the increasing product proliferation. To allow for this possibility, knowledge spillovers have to be modeled following the Schumpeterian framework.

The contribution of this article is twofold. First, an annual data set for a panel of 16 relatively homogeneous industrialized countries, which spans 137 years, is used to examine the productivity growth and productivity level effects of trade barriers and import penetration.[2] Because trade barriers and import penetration have fluctuated substantially over the last 137 years, the data yield ample identifying movements and, at the same time, enable one to control for country characteristics. Furthermore, it is tested whether openness has permanent or temporary output-growth effects.

Second, the article tests whether openness influences growth because it enables countries to import knowledge that is produced in other countries. Recent developments within endogenous growth theory suggest that openness influences growth through the channel of imports (Romer 1990, 1992; Grossman and Helpman 1991; Rivera-Batiz and Romer 1991; Aghion and Howitt 1998; Baldwin and Forslid 2000). Although some studies have investigated the relationship between growth and knowledge spillovers, very few, if any, have explicitly investigated the issue in the context of openness. Domestic patent applications are used in this article to construct domestic and foreign stocks of knowledge, and bilateral trade shares are used to quantify trade-related spillover effects. Spillover effects through the channel of imports follow the theories described in Grossman and Helpman (1991), whereby productivity is enhanced by imports of intermediate products that embody technological knowledge. Similarly, in the model of Rivera-Batiz and Romer (1991), countries can tap into world knowledge through the channel of imports. It follows that imports that contain technological knowledge may increase productivity in the importing country; whereas, imports of products that do not embody technology might not influence growth at all. A problem associated with the empirical estimates of these models, following the seminal paper of Coe and Helpman (1995), is that

[2] Edwards (1998) and O'Rourke (2000) are among the few studies that condition their output growth regressions on factors of production. Edwards (1998) uses TFP as the dependent variable for a cross-section sample of 93 countries over the period from 1950 to 1990. O'Rourke (2000) allows for land under cultivation and capital stock in his regressions; however, capital stock is proxied by coal consumption.

knowledge spillovers are assumed to have only level effects as opposed to permanent growth effects along a balanced growth path. The possibility that knowledge spillovers may have permanent growth effects following the predictions of Schumpeterian growth theories is allowed for in the empirical estimates in this article.

The literature is briefly surveyed in the next section, and the empirical framework and the empirical estimates are presented in sections 3 and 4. Sensitivity analysis is carried out in section 5, and section 6 concludes the article.

2. Trade Barriers, Openness, and Growth

Why should openness impact positively on growth? The traditional development literature considered exports as growth-enhancing because of the positive productivity spillovers from the tradable to the nontradable sector and because exports encourage more efficient investment projects (Edwards 1993). The recent endogenous growth literature has reoriented the argument as to how openness enhances growth from focusing on exports to emphasizing imports of knowledge (Romer 1990, 1992; Grossman and Helpman 1991; Rivera-Baltiz and Romer 1991; Baldwin and Forslid 2000). Barro and Sala-i-Martin (1995) argue that imports give domestic producers access to a wider variety of capital goods, thus effectively enlarging the efficiency of production.

The theories described in Grossman and Helpman (1991) suggest that the quality of intermediate products positively influences the efficiency of production. The new technology embodied in imported intermediate products renders imported products more productive and, therefore, increases labor productivity and total factor productivity (TFP). As a consequence, trade will enhance growth only to the extent that a country trades with research-intensive economies. The model of Barro and Sala-i-Martin (1995, ch. 8) considers a two-country world, where the technologically less advanced country taps into the knowledge of the technologically more advanced country. Provided that the costs of imitation are lower than the costs of innovation, the less advanced country will catch up to the more advanced country.

Although most theories predict that growth is impeded by trade barriers, some models predict that, under certain circumstances, trade barriers may be good for growth (see, for instance, the discussion by Rodrìguez and Rodrik 2000). Grossman and Helpman (1991) and Matsuyama (1992) show examples in which countries that are sufficiently far behind the technological frontier may, through imports, be driven toward production of traditional goods and, consequently, experience a lower growth rate. A closely related argument is that the host country needs a sufficiently high capacity to absorb the technology developed in the technologically more advanced countries (see, for instance, Howitt 2000). These models underscore the importance of using a sample of countries that are technologically not too far apart. The countries used in this article are quite homogenous in terms of economic development, length of schooling, and technological knowledge. We would, therefore, expect the theoretical prior to go in the direction in which trade barriers are bad for economic growth.

Empirically, some studies find a positive relationship between growth and openness; whereas, others do not. The studies of Dollar (1992), Ben-David (1993), Sachs and Warner (1995), Edwards (1998), Vamvakidis (1998), and Frankel and Romer (1999) are well-known studies that find a negative relationship between trade barriers and growth. Studies that fail to find a negative relationship between trade barriers and economic growth are the studies of Harrison and Hanson (1999), Rodrik (1999), O'Rourke (2000), Rodríguez and Rodrik (2000), Irwin (2002), Yanikkaya (2003), and, to some extent, Vamvakidis (2002). Harrison (1996) and Rodríguez and Rodrik (2000) argue that the results are sensitive to measurement of openness and inclusion of control variables. Furthermore, Vamvakidis (2002) argues that most studies find a positive relationship between growth and openness because the estimates rely predominantly on post-1970 data. Vamvakidis (2002) shows that the positive relationship between growth and openness is limited to the post-1970 period, and that no such relationship can be found in earlier data.

3. Empirical Framework

The empirical estimates in this article seek to be as inclusive as possible by including important control variables and time dummies that capture the effects of omitted variables that change by the same magnitude across countries over time. Furthermore, in addition to estimates covering the whole sample period, the estimation period is decomposed into three subperiods to examine whether the nexus between growth and openness is period specific. Instruments for openness are used to overcome potential endogeneity problems and error-in-variables biases.

The following model is estimated for a panel of 16 Organisation for Economic Co-operation and Development (OECD) countries:

$$\begin{aligned}\Delta \ln \mathrm{TFP}_{it} = {} & \alpha_0 + \alpha_1 Op_{it} + \alpha_2 \Delta Op_{it} + \alpha_3 \Delta \ln S^d_{it} + \alpha_4 \Delta \ln S^f_{it} + \alpha_5 \left(\frac{X}{Q}\right)^d_{it} + \alpha_6 \left(\frac{X}{Q}\right)^f_{it} \\ & + \alpha_7 m_{it} \left(\frac{X}{Q}\right)^f_{it} + TD + CD + \varepsilon_{1,it},\end{aligned} \tag{1}$$

where TFP is total factor productivity, Op is trade openness, S^d is the domestic stock of knowledge, S^f is the foreign stock of knowledge spillovers through the channel of imports, X is the productivity-adjusted innovative activity, Q is product variety, $(X/Q)^d$ is domestic research intensity, $(X/Q)^f$ is foreign research intensity spillovers through the channel of imports, m is nominal imports of goods as the share of nominal GDP, CD is fixed effect country dummies, TD is time dummies, ε is a disturbance term, Δ is a five-year difference operator, and the subscripts t and i signify time and country, respectively.[3] Trade openness, Op, is proxied by m or by the macro-tariff rate, Tr, which is measured as nominal import duties divided by the nominal import values of goods. Tariffs and the import penetration ratio are measured in decimal points. See Madsen (2008c) for unit root tests of the variables involved in the model, which reveal that all the variables in the model are stationary. Also see Madsen (2008c) for methods used to estimate technology spillovers through the channel of imports.

[3] Only direct knowledge transfers are allowed for in the estimates. Lumenga-Neso, Olarreaga, and Schiff (2005) advocate the importance of allowing for indirect knowledge transfer through the channel of imports. The indirect effect arises from the fact that imports of knowledge from country X to country Y are transmitted to country Z when country Z imports from country Y. Although indirect spillover effects are potentially important, it is beyond the scope of this article to consider these effects. More importantly, following endogenous growth theory, it is only the intermediate products from country X that are passed on to country Z, through country Y, that are relevant for knowledge spillovers. These product types cannot easily be identified by the historical data that are available.

In addition to imports of research intensity, the interaction between m and imports of research intensity has been added as a regressor in Equation 1. Although $(X/Q)^f$ consists of import-weighted knowledge stocks, as shown below, these weights are fractions that add up to one and, therefore, do not reflect openness. $(X/Q)^f$ is, therefore, multiplied by m to capture the role of international trade. The more open an economy is, the easier it is to tap into international knowledge. Note, however, that the stock of foreign knowledge, S^f, is not multiplied by m because it is already based on import weights that do not add up to one, as shown below. A term that allows for the interaction between m and S^f is included in the estimates in section 5.

The model is estimated in five-year differences to filter out business cycle influences. Quah and Rauch (1990) find that short-run cyclical fluctuations in import penetration and growth are highly correlated without necessarily showing any structural relationship. Inclusion of country dummies is not essential; the principal results are insensitive to whether or not they are included (the results are available from the author). Product variety is measured by employment because Schumpeterian models assume that product varieties follow the size of the population at the steady state. X is measured by the number of domestic patent applications, following Madsen (2008a). Patents are used because statistics on R&D expenditures or R&D workers are available for only a couple of countries before World War II and because the long historical R&D data are of bad quality.

Equation 1 is estimated using TFP, per capita output, Y/Pop, and output per hour worked, Y/H, as dependent variables. The advantage of using TFP as a dependent variable is that the growth effects of factor accumulation have been taken into account in the TFP estimates. Thus, TFP should, in principle, measure productivity. The advantages of using per capita output and output per hour worked is that no theory-dictated restrictions have been imposed on them and they are not influenced by measurement errors of land and capital. Furthermore, output per hour worked allows for TFP that has been derived under assumptions that may not apply over the whole period, such as perfect competition and constant returns to scale (see below for computation of TFP). Finally, the growth in TFP and in labor productivity is the same along the balanced growth path, provided that land is insignificant in production.[4] Per capita output is also used as a dependent variable to compare the results with those of most studies that measure productivity as per capita output. Per capita output is the least useful productivity measure of the three because it does not acknowledge the marked changes in annual working hours and labor force participation rates that have taken place over the past 137 years.

Equation 1 follows the predictions of second generation models of economic growth extended to allow for international trade (see Madsen 2008a for derivation). In the semi-endogenous growth models developed by Jones (1995), Kortum (1997), and Segerstrom (1998), a positive growth in R&D inputs is required to maintain sustained growth in TFP because of the assumption of diminishing returns to knowledge. This would suggest that growth in innovative activity is the key variable in explaining growth. Depreciation of the stock of

[4] Consider the constant returns to scale production function used in this article to estimate TFP: $Y = BK^{\alpha}T^{\beta}L^{1-\alpha-\beta}$, where B is productivity, K is capital, T is land area, and L is labor. Since Y/K is constant along a balanced growth path, the growth in output per worker, g_y, follows the following growth path: $g_y = \frac{1}{1-\alpha}g - \frac{\beta}{1-\alpha}\cdot n$, where n is the population growth rate and g is the rate of technological progress. Thus the growth in output per capita or output per hour worked is lower than TFP growth because of diminishing returns introduced by land as a fixed factor of production.

knowledge is allowed for in Equation 1, following Grossman and Helpman (1991) and Coe and Helpman (1995), so that it is the change in *net* research activity that is essential for growth. The Schumpeterian growth models of Aghion and Howitt (1998), Young (1998), and Howitt (1999) assume that R&D spreads more thinly across product varieties as the economy grows. To ensure sustained TFP growth, R&D has to increase over time to counteract the increasing range of products that lowers the productivity effects of R&D activity. The normalization of R&D by product varieties ensures that highly populated countries do not grow faster than small countries. It also ensures that proportionally higher R&D outlays, in terms of R&D expenditures, are required to maintain growth as the economy becomes richer. The larger an economy is, in terms of total output, the more likely it is that the R&D-induced product lines for a representative firm are replications of R&D-induced product lines of other firms. In other words, it is not the product variety but product quality that generates growth in Schumpeterian growth models.

Equation 1 is extended to allow knowledge spillovers through the channel of imports following Coe and Helpman (1995) and Madsen (2008a). Again the model distinguishes between the predictions of semi-endogenous growth theories and Schumpeterian growth models. Following the early endogenous growth literature, import penetration may influence growth positively because it enhances the potential for an importing country to tap into the world stock of knowledge (Romer 1990, 1992; Grossman and Helpman 1991; Rivera-Batiz and Romer 1991). The theories described in Grossman and Helpman (1991) suggest that the quality of intermediate products positively influences the efficiency of production. The new technology embodied in imported intermediate products increases productivity. As a consequence trade will enhance growth only to the extent that knowledge is embodied in the intermediate products that are imported from elsewhere. Several papers have found that the foreign stock of knowledge enhances TFP through the channel of imports (Coe and Helpman 1995; Coe, Helpman, and Hoffmaister 1997; Engelbrecht 1997; Lichtenberg and van Pottelsberghe de la Potterie 1998; Frantzen 2000; Guellec and van Pottelsberghe de la Potterie 2001, 2004; del Barrio-Castro, López-Bazo, and Serrano-Domingo 2002; Lumenga-Neso, Olarreaga, and Schiff 2005; Madsen 2007, 2008b). The method suggested by Lichtenberg and van Pottelsberghe de la Potterie (1998) is used to measure S_{it}^{f} (see Madsen 2008c for details).

The Coe-Helpman model has been extended to allow for research intensity spillovers through the channel of imports by Madsen (2008a). This allows for permanent growth effects of importing goods embodying research intensity following the predictions of Schumpeterian growth theory. This has important implications for the growth effects of imports of knowledge. Although the importation of knowledge has only level effects on productivity in the Coe-Helpman model, imports of goods embodying research intensity have permanent growth effects in the Schumpeterain model. See Madsen (2008c) for the measurement of $(X/Q)^{f}$.

Tr (tariff rates) and *m* (import penetration) are used as proxies for trade openness, noting that there is no universal measure of trade openness. The theoretical literature gives more attention to the relationship between trade policies and income growth rather than the relationship between trade and growth (Yanikkaya 2003). Furthermore, there is no clear consensus as to what represents openness or what is meant by openness and trade liberalization (Yanikkaya 2003). Anderson and Neary (1992) have constructed a trade restrictiveness index, which incorporates tariffs and nontariff trade barriers. Unfortunately, the data required to construct such a historical index are not available. The literature has predominantly focused on *m;* however, Rodríguez and Rodrik (2000) argue that *m* is not a good measure of trade barriers and recommend the use of *Tr* instead. Although *Tr* specifically measures trade barriers, *m* is influenced by several factors other than trade barriers and, as such, may be a bad proxy for trade barriers. As discussed by Edwards (1998), there are several ways in which *m* influences income, and, in that sense, the coefficient of *m* may not be very informative about causal factors.

Another issue is whether *Tr* and *m* are exogenous. The endogenous tariff literature has long advocated that tariffs are an outcome of endogenous forces (see, for example, Magee, Brock, and Young 1989). Furthermore, the propensity to import is heavily influenced by economic conditions. Madsen (2001) shows that the sharp reduction in world trade during the Great Depression was a result of increasing tariffs and nontariff trade barriers and decreasing income, which are all endogenous. Furthermore, Frankel and Romer (1999) argue that countries implementing free-market trade policies may also implement free-market policies in addition to implementing stable monetary and fiscal policies. The income effects of tariff policies in regression analysis may, therefore, be disguised by the income effects of other policies that are not controlled for in the regressions. Finally, Irwin (2002) argues that the negative relationship between growth and tariff rates, as often found in the growth literature, does not indicate anything about causality. To address this issue *Tr* and *m* are instrumented based on some of the instruments recommended by Trefler (1993) and Frankel and Romer (1999). The choice of instruments is discussed in the following subsection.

Equation 1 allows for the possibility that openness has permanent direct growth effects through the variable *Op* (openness), following most of the empirical literature on the nexus between growth and openness. In any event, it cannot automatically be taken for granted that openness has permanent growth effects. To satisfy the permanent growth-effects criteria in endogenous growth models, foreign knowledge must continuously produce a flow of ideas. In other words, there must be constant returns to the imported foreign knowledge stock. However, R&D knowledge spillovers through the channel of imports are already accounted for in the estimates. Thus the residual knowledge spillovers must stem from sources other than R&D or patents, such as human capital, or other sources unaccounted for, such as increasing competition and efficiency.

The estimates are corrected for serial correlation and heteroscedasticity using feasible least squares. Furthermore, to gain efficiency, the contemporary correlation between error terms across countries is allowed for in the estimates that cover the entire period from 1875 to 2006. Finally, the economy-wide TFP data are based on the three-factor homogenous Cobb-Douglas production technology (capital, land, and labor). See Madsen (2008c) for details on data computations.

Instruments for Tariffs and the Propensity to Import

As mentioned above, *Op* is proxied by *Tr* or *m.* Tariffs and the propensity to import are instrumented because they need not be exogenous and because they are proxies for trade openness and, as such, are measured by an error. Some of the instruments used here follow the suggestion of Trefler (1993) and Frankel and Romer (1999). Not all of their instruments are used here either because they are fixed over time for each individual country or because they are not available over the last 137 years. The following instruments are used for *Op:* population density (ratio of population to land area), time dummies, population size, rate of unemployment, change in the rate of unemployment, per capita mining gross domestic product (GDP), per capita agricultural production, per capita arable land, and rate of inflation. The change in population density and the population size are much influenced by fertility and death rates that are not strictly determined by growth. Sachs and Warner (1995) argue that countries with higher population densities are more likely to be open and have more international contacts. Frankel and Romer (1999) find that once population is controlled for, variables representing geography account for only a small proportion of the variations in trade.

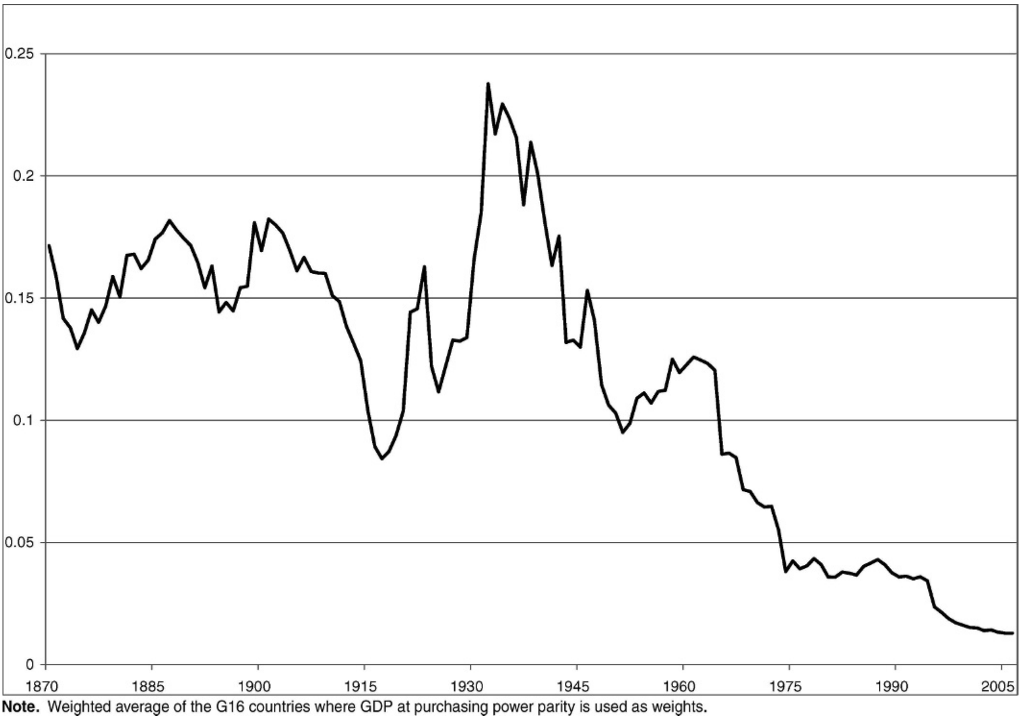
The literature on endogenous tariffs suggests that unemployment is an important determinant of tariffs (see Magee, Brock, and Young 1989). Trefler (1993) also notes that politicians insist that trade protection safeguards the livelihood of the potential unemployed in industries that are particularly threatened by international competition. Per capita agricultural GDP is included as an instrument because agricultural products have traditionally been subject to much higher tariff rates than other tradables, presumably because the agricultural lobby has been particularly strong (Madsen 2001). Per capita GDP in mining is included in the estimates because it is likely to be exogenous and a commodity that is often traded internationally. Finally, the rate of inflation serves as a potential important instrument for Tr because tariffs are often in fixed nominal values, which implies that tariff rates are reduced in periods of inflation and vice versa (see discussion below). Furthermore, a country that experiences inflation in excess of inflation among its trade partners will experience lobbying among firms for tariff escalations to be able to compete with the outside world (Magee, Brock, and Young 1989).

Data

The data cover 16 countries (G16) that have consistent data on macro-tariff rates, import penetration ratios, and variables used to compute TFP over the period from 1870 to 2006. These countries are Canada, the United States, Japan, Australia, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom.

Macro-tariff rates are measured as revenues from import duties divided by nominal imports of goods. Although macro-tariff rates suffer from the index number problem, where substitution away from imports of high- to low-tariff items mutes the mean and the variance of the average tariff rate, it is widely agreed that macro-tariff rates are good measures of tariff rates (Irwin 1998; O'Rourke 2000; Madsen 2001). Furthermore, Rodríguez and Rodrik (2000), who are among the strongest critics of the empirical literature on the nexus between growth and trade barriers, recommend tariff rates as measures of trade barriers.

Figure 1 displays the weighted average of the macro-tariff rate for G16 countries. The figure shows that tariff rates have changed substantially over the course of history, particularly when the index number problem is taken into account. Increasing tariffs can be identified over the following four periods: 1875–1890, 1918–1923, 1930–1935, and 1951–1960. The increasing tariffs during some of these periods were partly deflation induced. Madsen (2001) finds that almost half of the variations in the macro-tariff rates were price induced in the interwar period. This finding suggests that the tariff escalations in the 1880s, the beginning of the 1920s, and the 1930s were in part or entirely deflation induced, assuming that price changes were equally influential for tariff rates before World War I and during World War II. The finding also suggests that the tariff reductions during the world wars were inflation induced.



Note. Weighted average of the G16 countries where GDP at purchasing power parity is used as weights.

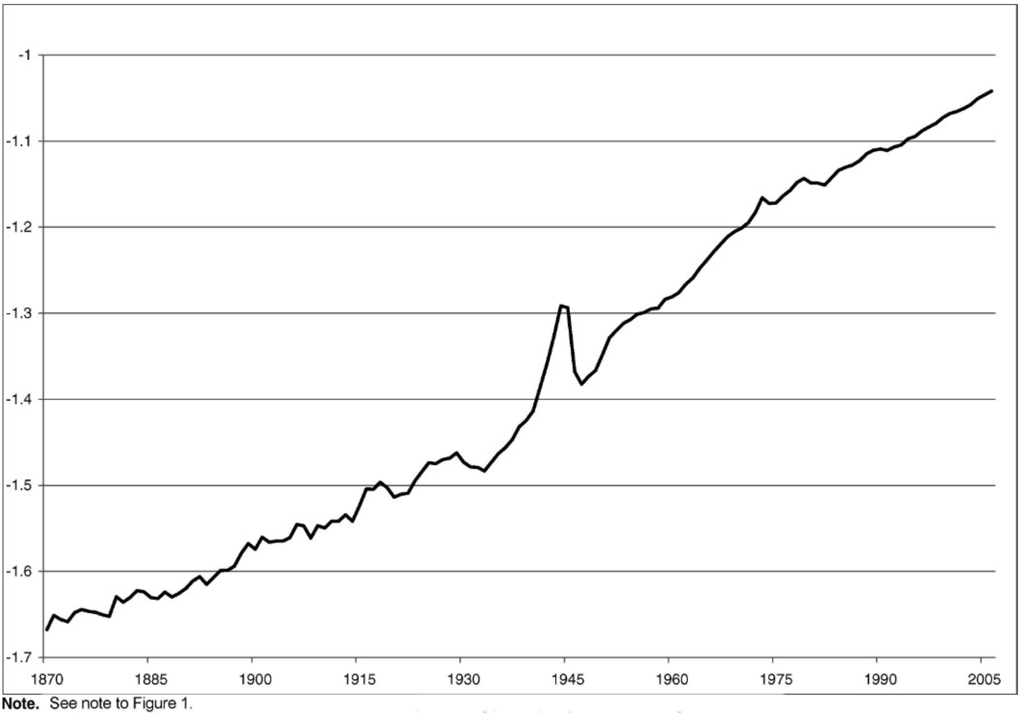
Figure 1. Macro-tariff Rate

The import penetration ratio is displayed in Figure 2. The ratio grew slowly during the globalization period from 1870 to 1913. Thereafter it declined markedly as a result of increasing nationalism, increasing trade barriers, and reduced or negative income growth (Madsen 2001). The 1913 level was not reestablished until the end of the 1970s. The post-1914 decline occurred in three abrupt stages: World War I, the Great Depression, and World War II. Measured in terms of import penetration, it is remarkable that the level of globalization, which resumed after World War II, has only recently reached the level that prevailed in 1913. Although the growth in services partly explains why the G16 countries are not more open today than they were a century ago, the figure nevertheless indicates that today's globalization is not historically unique. The decline in import penetration over the period from 1913 to 1945 and its slow recovery is more unusual than the level of import penetration that prevails today.

The average TFP for the G16 countries is displayed in Figure 3 (construction of TFP is detailed in Appendix 2). TFP has been increasing at a relatively constant rate over the whole period, except during the period 1948–1973, where the growth rate was exceptionally high. The growth in TFP coincides only partially with increasing import penetration (see Figure 2). The increasing openness over the period from 1870 to 1913 is associated with a steady increase in TFP. However, TFP continues its steady increase from 1913 to 1930 despite a significant reduction in openness during the same period. Conversely during the period from 1948 to 1973 the strong growth in TFP is associated with a significant increase in openness. The periods of rapid TFP growth are also only weakly associated with tariff reductions (Figure 1). During the period from 1890 to 1930 the macro-tariff rate followed a U-shaped path despite a relatively stable upward trend in TFP; however, the average tariff rate was reduced in the high growth period from World War II to 1973. Overall, the figures indicate a blurred relationship between

Note. Weighted average of the G16 countries where GDP at purchasing power parity is used as weights.

Figure 2. Propensity to Import



Note. See note to Figure 1.

Figure 3. TFP

Table 1. Parameter Estimates of the Restricted Version of Equation 1 in the Period 1875–2006

	1	2	3	4	5	6
	Y/Pop	*TFP*	*Y/H*	*Y/Pop*	*TFP*	*Y/H*
Tr	−1.763(10.8)	−0.177(1.18)	−0.212(1.16)			
ΔTr	0.870(7.40)	0.234(1.93)	0.543(4.46)			
m				−0.245(2.85)	−0.022(0.27)	−0.124(1.38)
Δm				2.000(3.46)	2.380(4.50)	0.055(0.10)
χ^2	0.02	0.01	0.06	0.02	0.03	0.05
DW	2.05	1.95	1.98	2.00	2.00	1.98
$R^2(B)$	0.90	0.77	0.89	0.69	0.76	0.85

The numbers in parentheses are absolute *t*-statistics. $R^2(B)$ is Buse's raw-moment R^2. χ^2 is the *p*-values of tests for overidentifying restrictions. The following instruments are used for tariffs and openness: The rate of unemployment, the change in the rate of unemployment, the growth in per capita agricultural GDP, the growth in per capita mining GDP, growth in consumer prices, the growth in per capita arable land, population growth, the change in population density, and time dummies. Time dummies and country dummies are included in the estimates but are not shown. The following data points are used: 1875, 1880, 1885, 1890, 1895, 1900, 1905, 1910, 1915, 1920, 1925, 1930, 1935, 1940, 1951, 1956, 1961, 1966, 1971, 1976, 1981, 1986, 1991, 1996, 2001, and 2006. m = propensity to import, *TFP* = total factor productivity, *Tr* = macro-tariff rate, *Y/H* = output per hour worked, and *Y*/Pop = per capita income.

TFP, tariffs, and import penetration, which suggests that factors other than openness have been influential for TFP growth.

The stock of knowledge and research activity are estimated using patent application count data because R&D data, which are used by Coe and Helpman (1995) and most of the subsequent literature, have become consistently available for the OECD countries only over the last couple of decades. Patent data, by contrast, have been consistently collected on an annual basis for almost all OECD countries since 1870 and are considered useful indicators of new knowledge (see, for instance, Griliches 1990). Because the time lag between the time at which a patent application is filed and eventually granted and the chance of success varies substantially over time and across countries, the estimates of the stock of knowledge and research activity are based on patents applied for. The stock of knowledge is computed using the inventory perpetual method on the domestic patent applications with a 20% geometric depreciation rate following the estimates by Pakes and Schankerman (1984). Patent data for 21 OECD member countries are used to construct S^f (data sources are available from the author upon request). These countries have, over the entire period considered, filed more than 90% of the patent applications in the world (WIPO 2002).

4. Estimation Results

Simple Regression Results

First, consider the estimates in Table 1, where the coefficients of all the research-related variables are restricted to zero. *Tr* and *m* are instrumented in all the estimates in this article except the estimates in the last table (Table 8). The tests for overidentifying restrictions do not reject the null hypothesis that the instruments are exogenous at the 7% level.[5] Consider the level

[5] The tests of overidentifying restriction regress the residuals from the IV regressions on the exogenous variables. The R^2 from these regressions is used to estimate nR^2, where n is the number of observations. Here, nR^2 is distributed as χ^2 under the null hypothesis that the instruments are exogenous.

effects of openness. Openness is measured by Tr in the first three columns in the table. The estimated coefficients of the level of Tr are negative; however, they are statistically significant only in the estimates in which productivity is measured in per capita terms. As discussed above, per capita is the least reliable measure of productivity advances of the three productivity measures because it fails to acknowledge changes in per capita hours worked and labor force participation. These results suggest that per capita output measures of productivity can give misleading results about the nexus between openness and growth. In the estimates in columns 4–6, where openness is measured by import penetration, the estimated coefficients of openness are statistically insignificant, except for the estimates where per capita output is a regressor. Overall these results suggest that openness does not have permanent productivity growth effects in this simple framework.

Turning to the estimated coefficients of the *change* in openness, the results contradict each other. The estimated coefficients of the change in Tr are significantly positive, suggesting that increasing tariffs bring productivity up to a higher level. Conversely, the estimated coefficients of the change in m are significantly positive in two of the three regressions, which is more in line with the predictions of standard models of growth and openness. These contradictory results indicate that Tr or m may be bad proxies for trade openness, that important control variables are omitted from the estimates, or that specification problems are present in the estimates. Furthermore, the coefficient estimates of Tr and m do not give any indication as to how openness influences growth. It is now investigated whether these results hold against the inclusion of control variables and changes in estimation periods.

Unrestricted Estimates of Equation 1

Unrestricted estimates of Equation 1 over the periods 1875–2006, 1956–2006, 1915–1951, and 1870–1910 are presented in Tables 2–5, respectively. The tests for overidentifying restrictions do not reject the null hypothesis that the instruments are exogenous at the 10% level. Consider first the estimates over the period 1875–2006 in Table 2. The estimated coefficients of Tr and ΔTr (columns 1–3) are generally of low statistical significance and with conflicting signs, which suggests that there is no clear direct relationship between growth and tariffs when knowledge and research intensity are allowed for in the estimates. The estimated coefficients of m in the estimates in columns 4–6 are statistically insignificant; whereas, the estimated coefficients of Δm are positive and mostly statistically significant. Overall, these results suggest that openness does not have any direct permanent growth effects but may have direct temporary positive growth effects.

The estimated coefficients of $\Delta \ln S^f$ are consistently positive and highly significant. Because $\Delta \ln S^f$ is based on the interaction between import penetrations and foreign stock of knowledge, this result suggests that openness has temporary growth effects, provided that the country trades with countries that have positive knowledge stocks. The estimated coefficients of $(X/Q)^f$ are in most cases insignificant; however, the estimated coefficients of $m(X/Q)^f$ are positive and often highly significant. This result suggests that foreign research intensity, conditional on import penetration, is influential for growth. The estimated coefficients of $(X/Q)^d$ are positive and highly significant, pointing toward strong growth effects of domestic research intensity. Finally, the estimated coefficients of $\Delta \ln S^d$ are positive and, in most cases, statistically significant.

Table 2. Parameter Estimates of Equation 1 in the Period 1875–2006

	1	2	3	4	5	6
	Y/Pop	*TFP*	*Y/H*	*Y/Pop*	*TFP*	*Y/H*
Tr	−1.387(7.31)	−0.159(0.79)	0.614(2.57)			
ΔTr	0.324(2.25)	0.073(0.50)	0.167(1.11)			
m				−0.185(2.04)	0.008(0.10)	−0.081(0.91)
Δm				1.857(3.21)	2.577(4.71)	0.355(0.61)
$\Delta \ln S^d$	0.023(2.41)	0.029(3.13)	0.018(1.67)	0.002(0.15)	0.019(2.16)	0.020(1.93)
$\Delta \ln S^f$	0.044(9.94)	0.029(6.86)	0.027(5.83)	0.044(10.83)	0.030(7.58)	0.029(6.16)
$(X/Q)^d$	0.007(2.18)	0.009(3.41)	0.016(4.42)	0.015(5.05)	0.010(3.99)	0.013(3.88)
$(X/Q)^f$	0.006(2.41)	−0.004(1.59)	0.003(1.20)	0.005(1.66)	−0.003(1.46)	0.002(0.90)
$m(X/Q)^f$	0.010(1.39)	0.022(3.08)	0.028(3.84)	0.011(1.57)	0.023(3.53)	0.031(4.09)
χ^2	0.01	0.01	0.04	0.02	0.02	0.05
DW	2.07	2.01	1.98	2.08	2.05	1.99
$R^2(B)$	0.90	0.79	0.88	0.89	0.78	0.88

See notes to Table 1. m = propensity to import, S^d = domestic knowledge stock, S^f = foreign knowledge spillovers through the channel of imports, TFP = total factor productivity, Tr = macro-tariff rate, $(X/Q)^d$ = domestic research intensity, $(X/Q)^f$ = foreign spillovers of research intensity through the channel of imports, Y/H = output per hour worked, and Y/Pop = per capita income.

In the estimates over the period from 1956 to 2006 in Table 3, the levels of tariffs have either positive or negative growth effects; whereas, the estimated coefficients of ΔTr are statistically insignificant. The estimates in columns 4–6 in Table 3 indicate that the level and change in import penetration have not been influential for growth over the last 50 years. The estimates show that research is essential for growth and that knowledge and research intensity spillovers through the channel of imports are important for growth. In summary, the estimates in Table 3 suggest that openness has been important for growth in the post–World War II period but that the beneficial effects of openness stem from knowledge spillovers.

The estimates in Table 4 over the period from 1915 to 1951 are interesting because they cover a period during which the world was exposed to two depressions and two world wars.

Table 3. Parameter Estimates of Equation 1 in the Period 1956–2006

	1	2	3	4	5	6
	Y/Pop	*TFP*	*Y/H*	*Y/Pop*	*TFP*	*Y/H*
Tr	−0.978(2.45)	0.682(1.74)	1.244(2.68)			
ΔTr	0.270(0.72)	0.342(0.92)	1.514(0.84)			
m				0.136(0.87)	0.066(0.42)	0.049(0.26)
Δm				1.392(1.76)	1.450(1.99)	−0.124(0.13)
$\Delta \ln S^d$	0.103(3.01)	0.038(1.14)	0.023(0.59)	0.095(2.75)	0.040(1.23)	0.048(1.27)
$\Delta \ln S^f$	0.097(7.08)	0.051(3.82)	0.055(3.55)	0.095(8.71)	0.061(6.30)	0.104(10.1)
$(X/Q)^d$	0.005(0.40)	0.032(2.62)	0.001(0.10)	0.000(0.02)	0.027(2.21)	−0.005(0.39)
$(X/Q)^f$	0.019(1.89)	0.007(0.77)	0.019(1.65)	0.023(2.33)	0.012(1.24)	0.032(2.68)
$m(X/Q)^f$	0.009(0.64)	−0.002(0.18)	0.016(1.24)	0.009(0.66)	0.012(1.25)	0.020(1.21)
χ^2	0.03	0.03	0.07	0.01	0.02	0.07
DW	1.85	1.78	1.81	1.92	1.80	1.84
$R^2(B)$	0.89	0.77	0.88	0.88	0.74	0.90

See notes to Table 1. m = propensity to import, S^d = domestic knowledge stock, S^f = foreign knowledge spillovers through the channel of imports, TFP = total factor productivity, Tr = macro-tariff rate, $(X/Q)^d$ = domestic research intensity, $(X/Q)^f$ = foreign spillovers of research intensity through the channel of imports, Y/H = output per hour worked, and Y/Pop = per capita income.

Table 4. Parameter Estimates of Equation 1 in the Period 1915–1951

	1	2	3	4	5	6
	Y/Pop	*TFP*	*Y/H*	*Y/Pop*	*TFP*	*Y/H*
Tr	−5.169(3.52)	−5.774(3.64)	−6.452(3.86)			
ΔTr	−0.030(0.07)	−0.414(0.94)	−0.304(0.61)			
M				−1.222(2.68)	−0.072(0.16)	0.204(0.39)
Δm				7.654(3.24)	7.786(3.37)	2.019(0.73)
$\Delta \ln S^d$	0.264(4.39)	0.187(2.83)	0.132(1.80)	0.246(3.75)	0.281(3.92)	0.178(2.13)
$\Delta \ln S^f$	0.027(3.13)	0.019(2.06)	0.012(1.01)	0.036(5.17)	0.028(3.43)	0.018(1.65)
$(X/Q)^d$	0.008(0.25)	0.024(0.65)	0.044(1.06)	0.014(0.41)	0.010(0.30)	0.038(0.95)
$(X/Q)^f$	0.006(0.41)	0.000(0.07)	0.005(0.28)	−0.008(0.63)	0.002(0.11)	0.011(0.60)
$m(X/Q)^f$	0.026(0.71)	0.004(0.10)	0.049(1.05)	0.037(1.15)	−0.010(0.26)	0.039(0.89)
χ^2	0.05	0.02	0.07	0.04	0.04	0.02
DW	1.90	1.85	1.82	1.95	1.95	1.85
$R^2(B)$	0.77	0.60	0.73	0.83	0.65	0.75

See notes to Table 1. m = propensity to import, S^d = domestic knowledge stock, S^f = foreign knowledge spillovers through the channel of imports, *TFP* = total factor productivity, Tr = macro-tariff rate, $(X/Q)^d$ = domestic research intensity, $(X/Q)^f$ = foreign spillovers of research intensity through the channel of imports, Y/H = output per hour worked, and Y/Pop = per capita income.

The regressions suggest that the tariff escalations during the period 1929–1932 had strong negative growth effects. The estimated coefficients of Tr are consistently highly significant and negative; whereas, the estimated coefficients of ΔTr are insignificant, thus pointing toward permanent negative growth effects of tariffs. Conversely, the estimated coefficients of m are insignificant; whereas, the estimated coefficients of Δm are positive and mostly significant. The estimated coefficients of $\Delta \ln S^d$ and $\Delta \ln S^f$ are positive and highly significant; whereas, the estimated coefficients of research intensity are insignificant.

Overall, these estimates give insight into an unusual growth process during the world wars and the interwar period. First, growth was significantly adversely affected by the escalating trade barriers shortly before the Great Depression and during the first half of the Great

Table 5. Parameter Estimates of Equation 1 in the Period 1875–1910

	1	2	3	4	5	6
	Y/Pop	*TFP*	*Y/H*	*Y/Pop*	*TFP*	*Y/H*
Tr	0.955(0.95)	0.902(1.08)	2.114(2.43)			
ΔTr	−0.391(0.65)	−0.328(0.69)	−0.598(1.09)			
M				−0.347(1.20)	−0.230(1.03)	−0.494(1.96)
Δm				2.972(1.16)	2.936(1.24)	3.165(1.40)
$\Delta \ln S^d$	0.021(1.26)	0.051(3.64)	0.040(2.55)	0.018(1.10)	0.045(3.03)	0.043(2.65)
$\Delta \ln S^f$	0.077(3.94)	0.052(2.74)	0.052(2.41)	0.067(3.38)	0.043(2.32)	0.040(1.93)
$(X/Q)^d$	0.007(1.02)	0.001(0.27)	0.008(1.38)	0.009(1.21)	0.002(0.42)	0.012(1.62)
$(X/Q)^f$	−0.024(1.88)	−0.017(1.42)	−0.013(0.88)	−0.026(1.93)	−0.018(1.46)	−0.014(0.87)
$m(X/Q)^f$	0.029(2.26)	0.052(4.12)	0.032(2.36)	0.031(2.12)	0.056(4.00)	0.035(2.54)
χ^2	0.02	0.03	0.03	0.01	0.02	0.05
DW	1.85	1.81	1.78	1.74	1.74	1.76
$R^2(B)$	0.82	0.77	0.89	0.82	0.75	0.88

See notes to Table 1. m = propensity to import, S^d = domestic knowledge stock, S^f = foreign knowledge spillovers through the channel of imports, *TFP* = total factor productivity, Tr = macro-tariff rate, $(X/Q)^d$ = domestic research intensity, $(X/Q)^f$ = foreign spillovers of research intensity through the channel of imports, Y/H = output per hour worked, and Y/Pop = per capita income.

Depression. Second, the negative growth effects of trade barriers were reinforced by the reduced knowledge spillovers through the channel of imports. Third, research activity did not have permanent, but temporary, growth effects during that period, which may be a result of the large gyrations in output and productivity during that period. This may have blurred the genuine relationship between productivity growth and foreign and domestic research intensity.

Finally, consider the estimates over the period from 1875 to 1913 in Table 5. Only one of the estimated coefficients of ΔTr, Tr, Δm, and m is significant at conventional significance levels. This result is consistent with the results from pre–World War I estimates in the literature (Bairoch 1972; Capie 1994; Foreman-Peck 1995; O'Rourke 2000, Clements and Williamson 2001; Irwin 2002; Irwin and Terviö 2002; Vamvakidis 2002). Furthermore, the estimates indicate that domestic and foreign research activity was influential for growth during that period. The estimated coefficients of the domestic and the foreign stock of knowledge and imports of research intensity are almost all highly significant.

Overall the estimates suggest the absence of direct productivity effects of openness over the last 137 years except during the interwar period and the world wars, during which tariff had permanent adverse productivity growth effects. The estimates, however, show that knowledge spillovers through the channel of imports were influential for growth for all periods considered. Furthermore, the estimates indicate that R&D intensity has permanent growth effects, which are consistent with the predictions of Schumpeterian growth theories and the findings of Madsen (2008a).

5. Sensitivity Analyses

To test for the sensitivity of the results to model specification, Equation 1 is extended to allow for the investment ratio and the interaction between import penetration and international knowledge spillovers. Furthermore, ordinary least squares (OLS) estimates of Equation 1 are undertaken in this section. First, the following two equations are estimated:

$$\begin{aligned}\Delta \ln \mathrm{TFP}_{it} = {} & \beta_0 + \beta_1 Op_{it} + \beta_2 \Delta Op_{it} + \beta_3 \Delta \ln S^d_{it} + \beta_4 \Delta \ln S^f_{it} + \beta_5 \left(\frac{X}{Q}\right)^d_{it} + \beta_6 \left(\frac{X}{Q}\right)^f_{it} \\ & + \beta_7 m_{it} \left(\frac{X}{Q}\right)^f_{it} + \beta_8 \left(\frac{1}{Y}\right)_{it} + TD + CD + \varepsilon_{2,it},\end{aligned} \tag{2}$$

and

$$\begin{aligned}\Delta \ln \mathrm{TFP}_{it} = {} & \gamma_0 + \gamma_1 Op_{it} + \gamma_2 \Delta Op_{it} + \gamma_3 \Delta \ln S^d_{it} + \gamma_4 \Delta \ln S^f_{it} + \gamma_5 \left(\frac{X}{Q}\right)^d_{it} + \gamma_6 \left(\frac{X}{Q}\right)^f_{it} \\ & + \gamma_7, m_{it} \left(\frac{X}{Q}\right)^f_{it} + \gamma_8 \Delta\left(m_{it} \ln S^f_{it}\right) + TD + CD + \varepsilon_{3,it},\end{aligned} \tag{3}$$

where I is real nonresidential investment and Y is real GDP. Equation 2 is Equation 1 augmented with the investment ratio to allow for transitional dynamics, noting that the growth effects of knowledge and knowledge spillovers are derived from growth models along their balanced growth paths. Equation 3 is Equation 1 augmented to allow for the interaction between import penetration and foreign knowledge. Following the lead of Coe and Helpman

Table 6. Parameter Estimates of Equation 2 in the Period 1875–2006

	1	2	3	4	5	6
	Y/Pop	*TFP*	*Y/H*	*Y/Pop*	*TFP*	*Y/H*
I/Y	0.167(3.38)	−0.024(0.54)	0.089(1.88)	0.212(4.38)	−0.023(0.47)	0.067(1.01)
Tr	−1.276(6.59)	−0.174(0.85)	0.658(2.70)			
ΔTr	0.334(2.35)	0.068(0.48)	0.186(1.24)			
m				−0.195(2.18)	0.013(0.15)	−0.076(0.84)
Δm				1.811(3.22)	2.550(4.61)	0.245(0.58)
$\Delta \ln S^d$	0.030(3.14)	0.028(2.99)	0.022(2.03)	0.011(1.10)	0.018(1.99)	0.023(2.24)
$\Delta \ln S^f$	0.043(9.79)	0.029(6.84)	0.027(5.84)	0.044(10.9)	0.031(7.55)	0.029(6.16)
$(X/Q)^d$	0.007(2.30)	0.010(3.39)	0.015(4.09)	0.014(4.81)	0.010(3.87)	0.012(3.42)
$(X/Q)^f$	0.005(1.90)	−0.003(1.49)	0.003(1.12)	0.003(1.21)	−0.002(0.78)	0.019(0.85)
$m(X/Q)^f$	0.016(2.07)	0.021(2.81)	0.030(4.01)	0.018(2.51)	0.024(3.24)	0.032(4.21)
χ^2	0.01	0.02	0.03	0.02	0.03	0.02
DW	2.07	2.00	1.99	2.08	2.05	2.00
$R^2(B)$	0.91	0.79	0.88	0.89	0.79	0.88

See notes to Table 1. m = propensity to import, S^d = domestic knowledge stock, S^f = foreign knowledge spillovers through the channel of imports, *TFP* = total factor productivity, *Tr* = macro-tariff rate, $(X/Q)^d$ = domestic research intensity, $(X/Q)^f$ = foreign spillovers of research intensity through the channel of imports, *Y/H* = output per hour worked, and *Y*/Pop = per capita income.

(1995), most of the subsequent empirical literature has included this interaction term in their regressions. Coe and Helpman (1995) multiplied m and ln S^f to capture the role of international trade. They argued that although S^f consists of import-weighted knowledge stocks, these weights are fractions that add up to one and, therefore, do not reflect openness. The weights used in this article to construct S^f, which are based on the weighting scheme of Lichtenberg and van Pottelsberghe de la Potterie (1998), do not add up to one; however, they are influenced by import penetration, as argued above. Thus, the variable m_{it} ln S^f_{it} counts import penetration twice. Here m and ln S^f are multiplied to investigate whether knowledge spillovers through the channel of imports influence growth in a nonlinear fashion.

The results of estimating Equation 2 are displayed in Table 6. The tests for overidentifying restrictions do not reject the null hypothesis that the instruments are exogenous at the 5% level. The estimated coefficient of the investment ratio is significant only in the estimates where the dependent variable is per capita output, which suggests that I/Y is not capturing transitional dynamics but is correlated with the labor force participation rate and hours worked. The parameter estimates of the other regressors are almost unaffected by the inclusion of the investment ratio.

The results of estimating Equation 3 are presented in Table 7. The tests for overidentifying restrictions do not reject the null hypothesis that the instruments are exogenous at the 5% level. The estimated coefficient of m ln S^f is statistically significant in most cases. Coupled with the fact that the estimated coefficient of ln S^f remains statistically highly significant, this result suggests that an independent effect on growth comes from import penetration. In other words, the more open is the economy, the stronger is its capacity to absorb knowledge that is produced elsewhere. Furthermore, the estimates suggest that the spillover effect is increasing more than proportionately with import penetration, since import penetration influences knowledge spillovers in a nonlinear fashion.

The estimated coefficients of $m(X/Q)^{\mathrm{f}}$ are highly significant in the estimates where productivity is measured as TFP or output per hour worked. This suggests that the capacity of

Table 7. Parameter Estimates of Equation 3 in the Period 1875–2006

	1	2	3	4	5	6
	Y/Pop	*TFP*	*Y/H*	*Y/Pop*	*TFP*	*Y/H*
$\Delta(m\ lnS^f)$	0.010(1.79)	0.026(4.42)	0.012(1.82)	0.006(1.21)	0.020(3.53)	0.011(1.81)
Tr	−1.379(7.30)	−0.169(0.84)	0.593(2.48)			
ΔTr	0.379(2.55)	0.181(1.27)	0.220(1.44)			
M				−0.184(2.03)	0.001(0.02)	−0.089(1.01)
Δm				1.836(3.17)	2.268(4.18)	0.231(0.39)
$\Delta \ln S^d$	0.025(2.57)	0.032(3.51)	0.019(1.82)	0.003(0.26)	0.021(2.48)	0.021(2.06)
$\Delta \ln S^f$	0.041(7.94)	0.021(4.44)	0.022(4.18)	0.041(9.00)	0.024(5.33)	0.025(4.62)
$(X/Q)^d$	0.007(2.05)	0.009(3.35)	0.015(4.09)	0.015(5.01)	0.010(3.87)	0.012(3.62)
$(X/Q)^f$	0.006(2.34)	−0.005(2.07)	0.003(1.14)	0.005(1.59)	−0.004(1.86)	0.002(0.85)
$m(X/Q)^f$	0.011(1.56)	0.023(3.36)	0.029(3.98)	0.011(1.65)	0.026(3.75)	0.031(4.18)
χ^2	0.03	0.02	0.05	0.05	0.01	0.03
DW	2.06	1.99	1.99	2.08	2.04	2.00
$R^2(B)$	0.92	0.81	0.88	0.89	0.79	0.88

See notes to Table 1. m = propensity to import, S^d = domestic knowledge stock, S^f = foreign knowledge spillovers through the channel of imports, TFP = total factor productivity, Tr = macro-tariff rate, $(X/Q)^d$ = domestic research intensity, and $(X/Q)^f$ = foreign spillovers of research intensity through the channel of imports, Y/H = output per hour worked, and Y/Pop = per capita income.

a country to take advantage of the research intensity among its trade partners is an increasing function of import penetration. Note that the estimated coefficients of $(X/Q)^f$ have gone from being statistically significant in Table 1 to being insignificant in Table 7. This reinforces the result that the opportunity to import research intensity from trade partners depends positively on imports. Finally, the estimated coefficients of openness have hardly been affected by the inclusion of the interaction terms, which shows that the results obtained in the previous section are robust to inclusion of other control variables.

Finally, Equation 1 is estimated using OLS over the period from 1875 to 2006. The tests for overidentifying restrictions do not reject the null hypothesis that the instruments are exogenous at the 5% level. The results, which are reported in Table 8, are very close to the instrumental variables (IV) estimates in Table 1. The estimated coefficients of Tr and ΔTr (columns 1–3) are insignificant except for the estimated coefficient of ΔTr in the third column. The estimated coefficients of m in the estimates in columns 4–6 are statistically insignificant, while the estimated coefficients of Δm are positive and mostly statistically significant. The knowledge variables remain significant, as in the other regressions. Overall the estimation results are quite similar to the estimates in Table 1, and this suggests that the results are fairly insensitive to whether or not instruments are used in the regressions.

6. Conclusion and Implications of the Findings

This article argues that simple models relating per capita GDP growth to the level of tariffs and openness may not uncover a genuine relationship between growth and trade barriers. This is because important conditional variables may be omitted from the regressions and because the interaction between imports and the foreign stock of technology is not allowed for in such models. Estimates in this article based on a simple model relating productivity and openness

Table 8. OLS Estimates of Equation 1 in the Period 1875–2006

	1	2	3	4	5	6
	Y/Pop	*TFP*	*Y/H*	*Y/Pop*	*TFP*	*Y/H*
Tr	0.010(0.30)	0.032(1.03)	0.053(1.42)			
ΔTr	0.073(1.65)	−0.053(1.29)	−0.184(4.14)			
m				−0.033(0.59)	0.009(0.15)	−0.116(1.82)
Δm				0.174(3.37)	0.206(3.66)	0.163(2.50)
$\Delta \ln S^d$	0.010(0.88)	0.022(2.47)	0.019(1.77)	0.012(1.11)	0.027(3.19)	0.018(1.68)
$\Delta \ln S^f$	0.046(11.1)	0.029(6.93)	0.025(5.58)	0.042(10.6)	0.027(6.78)	0.027(5.52)
$(X/Q)^d$	0.016(5.06)	0.009(3.72)	0.012(3.71)	0.013(4.21)	0.010(3.78)	0.011(3.29)
$(X/Q)^f$	0.006(2.10)	−0.003(1.29)	0.003(1.09)	0.008(2.46)	−0.004(1.20)	0.006(2.05)
$m(X/Q)^f$	0.069(0.97)	0.022(3.00)	0.003(4.40)	0.005(0.44)	0.023(2.20)	0.014(1.26)
DW	2.07	2.00	2.02	2.07	1.99	1.99
$R^2(B)$	0.88	0.81	0.89	0.89	0.82	0.88

See notes to Table 1. m = propensity to import, S^d = domestic knowledge stock, S^f = foreign knowledge spillovers through the channel of imports, TFP = total factor productivity, Tr = macro-tariff rate, $(X/Q)^d$ = domestic research intensity, and $(X/Q)^f$ = foreign spillovers of research intensity through the channel of imports, Y/H = output per hour worked, and Y/Pop = per capita income.

confirm the findings in the literature that productivity growth tends to be unrelated to tariffs and the propensity to import.

Extending the model to allow for the influence on productivity growth of the growth in domestic and foreign knowledge stock and research intensity through the channel of imports changes the results in important ways. The estimated coefficients of openness, measured by tariff rates and import penetration, remained mostly insignificant, except for the period 1915–1951, during which the level of tariff rates had significant negative effects on productivity growth. However, openness is influential for productivity growth once the interaction between the propensity to import and foreign knowledge stock or research intensity is allowed for in the estimates. First, the estimated coefficients of the interaction between the propensity to import and trade-weighted research intensity were mostly highly significant. Second, the growth in foreign knowledge through the channel of imports was highly influential for productivity growth. Furthermore, the interaction between the growth in the import of knowledge through the channel of imports and the propensity to import was influential for growth. This reinforces the findings that openness is important for growth when conditioned on knowledge spillovers. These results are powerful because they show (i) that the positive relationship between imports of technology and growth is not spuriously driven by openness and (ii) that openness is not a virtue in its own right but that trade needs to be targeted at products that embody technological knowledge before a country can benefit from trade.

Another noteworthy result is that tariff rates had markedly negative effects on growth during the period 1915–1951, a period that covers two depressions and two world wars. The tariff escalations over the period from 1916 to 1932 contributed significantly to a reduction in the growth rates during that period. Simulations of the models suggest that tariffs reduced productivity growth by 0.7% on an annual basis. This figure suggests that, although the tariff escalations at the onset of the Great Depression contributed to the Depression, they cannot stand alone as factors that were responsible for the Great Depression, as claimed by Meltzer (1976).

The findings that the interaction between the propensity to import and research intensity were influential for productivity growth suggest that openness can have permanent growth effects as long as a country's trading partners undertake at least some research. The measure used for research intensity in this article, namely, patents applied for per worker, has been relatively constant over the past century. This implies that the increasing propensity to import since the end of World War II has increased the contribution of foreign research intensity to productivity growth. This may partly explain the productivity convergence among the OECD countries that has intensified since the end of World War II.

The question is whether the results are limited to the OECD countries, or whether they can be generalized to developing countries, particularly the poorest developing countries. Coe, Helpman, and Hoffmaister (1997) find significant knowledge spillovers through the channel of imports from North to South, which suggests that the findings in this article, to some extent, operate effectively for developing countries. However, whether the interaction between the propensity to import and research intensity influences growth in developing countries has thus far not been tested. A problem facing the low-income developing countries is that they do not as yet have the educational- and research-related capacity to exploit effectively the technology that has been developed elsewhere. Future research in this area should shed some light on this issue.

Appendix 1: Instrument Variable Regression

Table A1 shows the results from the first-stage IV regressions. The estimated coefficients are generally significant in the regressions in which Tr and m are measured in levels and the R^2 are of acceptable levels. This suggests that the instruments for Tr and m are potentially useful. The R^2 are on the lower side in the regressions in which ΔTr and Δm are dependent variables, and most of the estimated coefficients of the nondeterministic variables are insignificant. These results suggest that the instruments used for ΔTr and Δm are not of high quality and that they may potentially give misleading coefficient estimates of ΔTr and Δm. However, because the OLS estimates in Tables 1–8 are almost identical to the IV estimates, the potential bias introduced by the use of bad instruments is unlikely to be significant.

Table A1. Absolute t-Ratios Associated with the Instruments in the First Round Regression

	Tr	ΔTr	M	Δm
U	1.84	0.65	1.97	0.31
ΔU	1.54	0.20	0.22	0.20
ΔMin	2.31	0.61	1.29	0.92
ΔLandp	2.84	1.87	2.99	0.65
ΔAgr	0.79	0.10	1.87	1.14
π	0.36	6.19	1.42	0.74
ΔPden	2.06	0.89	3.61	0.04
Pop	1.03	0.50	9.22	0.15
R^2	0.32	0.21	0.47	0.29

Agr = per capita agricultural production, Landp = per capita arable land, Min = per capita mining GDP, Pden = population density, Pop = population size, U = the rate of unemployment, π = the five-year inflation rate, and Δ = five-year difference estimator. Time dummies and constant terms are included in the regressions but not shown.

Appendix 2: TFP Data Source

The economy-wide TFP data are based on the three-factor homogenous Cobb-Douglas production technology. Following the Divisa-Törnqvist method, the land shares are allowed to vary over time and across countries:

$$TFP_{it} = \frac{Y_{it}^{r}}{L_{it}^{(1-\alpha)} K_{it}^{\alpha(1-s_{it})} T_{it}^{as_{it}}}, \tag{A1}$$

where Y^r is real GDP, L is labor inputs (annual hours worked times economy-wide employment), K is capital stock, T is land area under cultivation, $(1 - \alpha)$ is labor's income share for country *i,* and *s* is the agricultural sector's share of the economy-wide GDP, which is allowed to vary across countries and over time. Labor's income share is calculated as the economy-wide compensation to employees divided by nominal GDP, where labor's compensation is corrected for imputed payments to the self-employed and the data are calculated as far back in history as income share data are available (data are available from the author upon request). This correction is essential because earnings from self-employment in national accounts are counted as profits and, consequently, do not count as labor income earned by the employment of self-employed. To correct for this bias the average earning per employee, multiplied by the number of self-employed, is added to the compensation of employees. Labor inputs are measured as annual hours worked per worker multiplied by economy-wide employment, as opposed to population, to cater for the fact that the labor force participation rate and annual hours worked have changed substantially over the past 137 years.

The division of output elasticities between land and capital follows the method suggested by Denison (1967, p. 41), in which the output elasticity of land is measured as the share of agriculture in total GDP. While land is not an important factor of production for the industrial countries today, it was an essential production factor before the mid-20th century. The unweighted average of the share of agriculture in total GDP has declined from 37% in 1870 to 2% in 2002 for G16 countries. This underscores the importance of including land as a factor of production in the TFP estimates that go far back in history.

For other data sources see Madsen (2008c).

References

Aghion, Philippe, and Peter Howitt. 1998. *Endogenous growth*. Cambridge, MA: MIT Press.

Anderson, James E., and J. Peter Neary. 1992. Trade reform with quotas, partial rent retention, and tariffs. *Econometrica* 60:57–76.

Bairoch, Paul. 1972. Free trade and European economic development in the 19th century. *European Economic Review* 3:211–45.

Baldwin, Richard E., and Rikard Forslid. 2000. Trade liberalization and endogenous growth: A *q*-theory approach. *Journal of International Economics* 50:497–517.

Barro, Robert J., and Xavier Sala-i-Martin. 1995. *Economic growth*. New York: McGraw-Hill.

Ben-David, Dan. 1993. Equalizing exchange: Trade liberalization and income convergence. *Quarterly Journal of Economics* 108:653–79.

Capie, Forest. 1994. *Tariffs and growth: Some insights from the world economy, 1850–1940*. Manchester, UK: Manchester University Press.

Clements, Michael A., and Jeffrey G. Williamson. 2001. A tariff-growth paradox? Protection's impact the world around 1875–1997. NBER Working Paper No. 8459.

Coe, David T., and Elhanan Helpman. 1995. International R&D spillovers. *European Economic Review* 39:859–87.

Coe, David T., Elhanan Helpman, and Alexander W. Hoffmaister. 1997. North-south R&D spillovers. *Economic Journal* 107:134–49.

Del Barrio-Castro, Thomás, Enrique López-Bazo, and Guadalupe Serrano-Domingo. 2002. New evidence on international R&D spillovers, human capital and productivity in the OECD. *Economics Letters* 77:41–45.

Denison, Edward F. 1967. *Why growth rates differ*. Washington, DC: Brookings Institution.

Dollar, David. 1992. Outward-oriented developing economies really do grow more rapidly: Evidence from 95 LDCs, 1976–85. *Economic Development and Cultural Change* 40:523–44.

Edwards, Sebastian. 1993. Openness, trade liberalization, and growth in developing countries. *Journal of Economic Literature* 111:1358–93.

Edwards, Sebastian. 1998. Openness, productivity and growth: What do we really know? *Economic Journal* 108:383–98.

Engelbrecht, Hans-Jürgen. 1997. International R&D spillovers, human capital and productivity in the OECD economies: An empirical investigation. *European Economic Review* 41:1479–88.

Foreman-Peck, James. 1995. A model of later nineteenth century European economic development. *Revista de Historia Econòmia* 13:441–71.

Frankel, Jeffrey A., and David Romer. 1999. Does trade cause growth? *American Economic Review* 89:379–99.

Frantzen, Dirk. 2000. R&D, human capital and international technology spillovers: A cross-country analysis. *Scandinavian Journal of Economics* 102:57–75.

Griliches, Zvi. 1990. Patent statistics as economic indicators: A survey. *Journal of Economic Literature* 107:1661–1707.

Grossman, Gene, and Elhanan Helpman. 1991. *Innovations and growth in the global economy*. Cambridge, MA: MIT Press.

Guellec, Dominique, and Bruno van Pottelsberghe de la Potterie. 2001. The internationalisation of technology analysis with patent data. *Research Policy* 30:1253–66.

Guellec, Dominique, and Bruno van Pottelsberghe de la Potterie. 2004. From R&D to productivity growth: Do the institutional setting and the source of funds of R&D matter? *Oxford Bulletin of Economics and Statistics* 66:353–78.

Harrison, Ann. 1996. Openness and growth: A time-series, cross-country analysis for developing countries. *Journal of Development Economics* 48:419–47.

Harrison, Ann, and Gordon Hanson. 1999. Who gains from trade reform? Some remaining puzzles. *Journal of Development Economics* 50:125–54.

Howitt, Peter. 1999. Steady endogenous growth with population and R&D growing. *Journal of Political Economy* 107:715–30.

Howitt, Peter. 2000. Endogenous growth and cross-country income differences. *American Economic Review* 90:829–46.

Irwin, Douglas A. 1998. Changes in U.S. tariffs: The role of import prices and commercial policies. *American Economic Review* 88:1015–26.

Irwin, Douglas A. 2002. Interpreting the tariff-growth correlation of the late 19th century. *American Economic Review, Papers and Proceedings* 92:165–9.

Irwin, Douglas A., and Marko Terviö. 2002. Does trade raise income? Evidence from the twentieth century. *Journal of International Economics* 58:1–18.

Jones, Charles I. 1995. R&D based models of economic growth. *Journal of Political Economy* 103:759–84.

Kortum, Samuel. 1997. Research, patenting, and technological change. *Econometrica* 65:1389–1419.

Lichtenberg, Frank R., and Bruno van Pottelsberghe de la Potterie. 1998. International R&D spillovers: A comment. *European Economic Review* 42:1483–91.

Lumenga-Neso, Olivier, Marcelo Olarreaga, and Maurice Schiff. 2005. On 'indirect' trade-related R&D spillovers. *European Economic Review* 49:1785–98.

Madsen, Jakob B. 2001. Trade barriers and the collapse of world trade during the great depression. *Southern Economic Journal* 67:848–68.

Madsen, Jakob B. 2007. Technology spillover through trade and TFP convergence: 135 years of evidence for the OECD countries. *Journal of International Economics* 72:464–80.

Madsen, Jakob B. 2008a. Semi-endogenous models versus Schumpeterian theory: International evidence over a century. *Journal of Economic Growth* 13:1–26.

Madsen, Jakob B. 2008b. Economic growth and world exports of ideas: A century of evidence. *Scandinavian Journal of Economics* 110:145–67.

Madsen, Jakob B. 2008c. Trade barriers, openness, and economic growth. Working Paper No. 27-08, Department of Economics, Monash University.

Magee, Stephen P., William A. Brock, and Leslie Young. 1989. *Black hole tariffs and endogenous policy theory: Political economy in general equilibrium*. Cambridge, UK: Cambridge University Press.

Matsuyama, Kiminori. 1992. Agricultural productivity, comparative advantage, and economic growth. *Journal of Economic Theory* 58:317–34.

Meltzer, Allan H. 1976. Monetary and other explanations of the start of the great depression. *Journal of Monetary Economics* 2:455–71.

O'Rourke, Kevin. 2000. Tariffs and growth in the late 19th century. *Economic Journal* 110:456–83.

Pakes, Ariel, and Mark Schankerman. 1984. The rate of obsolescence of patents, research gestation lags, and the private rate of return to research resources. In *R&D, patents, and productivity*, edited by Zvi Griliches. Chicago: University of Chicago Press, pp. 73–88.

Quah, Danny, and James E. Rauch. 1990. Openness and the rate of economic growth. Unpublished paper, University of California, San Diego.

Rivera-Batiz, Luis, and Paul M. Romer. 1991. Economic integration and endogenous growth. *Quarterly Journal of Economics* 106:531–55.

Rodriguez, Francisco, and Dani Rodrik. 2000. Trade policy and economic growth: A skeptic's guide to cross-national evidence. In *NBER Macroeconomics Annual*, edited by Ben S. Bernanke and Kenneth S. Rogoff. Cambridge, MA: MIT Press, pp. 261–325.

Rodrik, Dani. 1999. *The new global economy and developing countries: Making openness work*. Washington, DC: Overseas Development Council.

Romer, Paul. 1990. Endogenous technological change. *Journal of Political Economy* 98:S71–S102.

Romer, Paul M. 1992. Two strategies for economic development: Using ideas and producing ideas. World Bank Annual Conference on Economic Development. Washington, DC: World Bank.

Sachs, Jeffrey, and Andrew Warner. 1995. Economic reform and the process of global integration. *Brookings Papers on Economic Activity* 1:1–118.

Segerstrom, Paul S. 1998. Endogenous growth without scale effects. *American Economic Review* 88:1290–1310.

Trefler, Daniel. 1993. Trade liberalization and the theory of endogenous protection: An econometric study of U.S. import policy. *Journal of Political Economy* 101:138–60.

Vamvakidis, Athanasios. 1998. Regional integration and economic growth. *World Bank Economic Review* 12:251–70.

Vamvakidis, Athanasios. 2002. How robust is the growth-openness connection? Historical evidence. *Journal of Economic Growth* 7:57–80.

World International Property Organization (WIPO). 2002. *100 years of industrial property statistics*. Geneva: WIPO.

Yanikkaya, Halit. 2003. Trade openness and economic growth: A cross-country empirical investigation. *Journal of Development Economics* 72:57–89.

Young, Alwyn. 1998. Growth without scale effects. *Journal of Political Economy* 106:41–63.