NBER WORKING PAPER SERIES

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Working Paper 22368
http://www.nber.org/papers/w22368

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
June 2016

We would like to thank Sebastian Hohmann for comments. Any errors are ours. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 22368
June 2016
JEL No. F10,G30,O40

ABSTRACT

Empirical cross-industry cross-country models are applied widely in economics, for example to investigate the determinants of economic growth or international trade. Estimation generally relies on US proxies for unobservable technological industry characteristics, for example industries' dependence on external finance or relationship-specific inputs. We examine the properties of the estimator and find that estimates can be biased towards zero (attenuated) or away from zero (amplified), depending on how technological similarity with the US covaries with other country characteristics. We also develop an alternative estimator that yields a lower bound on the true effect in cross-industry cross-country models of comparative advantage.

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1 Introduction

Recent empirical work in macroeconomics and international trade has relied extensively on cross-industry cross-country models that relate cross-country differences in industry performance – industry growth or industry exports for example – to an interaction between (i) country characteristics like financial development, institutional quality, or human capital endowments and (ii) industry characteristics like external-finance dependence, the complexity of production, or skill intensity. The approach has proven useful for examining a surprisingly wide variety of interesting economic questions, briefly reviewed below. Two strands of research stand out. First, following Rajan and Zingales (1998), cross-industry cross-country models have been used to examine how economic growth and development is affected by financial development, property rights protection, contract enforcement, and human capital endowments. Second, building on Romalis (2004) and subsequent theoretical contributions in international trade, cross-industry cross-country models have served as the basis for empirical studies of the effect of factor endowments and institutions on comparative advantage (for a review, see Nunn and Trefler, 2014). For example, Nunn (2007) uses the approach to show that better contract enforcement is a source of comparative advantage in industries that use relationship-specific inputs more intensively.

Because there is little industry data for most countries, the cross-industry cross-country literature generally treats the relevant technological industry characteristics – for example, external-finance dependence in Rajan and Zingales (1998) or relationship-specific input intensity in Nunn (2007) – as unobservable and employs proxies from a benchmark country, typically the United States (US). Another reason for using US industry data to obtain proxies for the relevant industry characteristics is that technological industry characteristics must be inferred from industry behavior, which is likely to yield more reliable results in countries where markets are not too distorted. Our goal here is to understand the widely used cross-industry cross-country estimator and formally analyze the implications of using data from a benchmark country to proxy unobservable technological industry characteristics.

Our starting point is an empirical framework that encompasses the cross-industry cross-country models in the literature. A basic feature of the framework is that the technological characteristics of industries may be more similar for some pairs of countries than others (e.g., Bernard and Jones, 1996; Acemoglu and Zilibotti, 2001; Schott, 2004; Caselli, 2005). We then show that the benchmarking estimator used in the cross-industry cross-country literature is subject to a bias shaped by two countervailing forces. Unsurprisingly, proxying the technological industry characteristics of countries using data from a benchmark country may result in a bias toward zero (an attenuation bias). The reasoning is similar to that of the classical measurement error bias. But benchmarking may also result in a bias away from zero, which we refer to as amplification bias. The amplification bias can be very strong if technologically similar countries are similar in other dimensions.[1]

A main area of application of cross-industry cross-country models is international trade, where these models have been used to examine the effect of factor endowments and institutions on comparative advantage (e.g. Romalis, 2004; Levchenko, 2007; Nunn, 2007; Cuñat and Melitz, 2012; Krishna and Levchenko, 2013; Manova, 2013). We show that in this context there is a benchmarking estimator that is biased towards zero and therefore yields a lower bound on the true effect, as long as some countries differ in the direction of their comparative advantage. We illustrate this estimator by applying it to Nunn's (2007) study of the effect of contract enforcement on comparative advantage in industries that depend more on relationship-specific intermediate inputs.

The rest of the paper is structured as follows. Next we briefly review some of the applications of the cross-industry cross-country approach. Section 2 examines the estimator used in the cross-industry cross-country literature. Section 3 develops the alternative estimator that yields a lower bound on the true effect in models of comparative advantage and illustrates the estimator in the context of Nunn (2007). Section 4 concludes.

Some Applications of the Cross-Industry Cross-Country Approach The cross-industry cross-country approach is widely used in economics and our brief review here is only meant to illustrate the range of empirical applications. See Appendix Table 1 for a summary of the variety of applications.

Many applications of the cross-industry cross-country approach investigate the effects of financial markets on economic growth, firm entry and exit, investment, and innovation (e.g., Rajan and Zingales, 1998; Fisman and Love, 2003, 2007; Braun and Larrain, 2005; Aghion, Fally, and Scarpetta, 2007; Beck, Demirgüc-Kunt, Laeven, and Levine, 2008; Brown, Martinson, and Petersen, 2013; Hsu, Tian, and Xu, 2014; Calomiris, Larrain, Liberti, and Sturgess, 2016).

The cross-industry cross-country approach has been widely used to examine the determinants of international trade and industrial specialization. Nunn (2007), Levchenko (2007), and subsequent works show that institutionally advanced countries tend to specialize in sec-

[1] It is tempting to think of the amplification bias as a simple omitted variable bias, but there are differences that make this analogy less useful. For example, the two forces determining the bias of the benchmarking estimator result in either amplification or attenuation. In contrast, the simple omitted variable bias is either upwards or downwards. Nevertheless, the bias of the benchmarking estimator can – just like the classical measurement error bias – be understood as a nonstandard omitted variable bias.

tors that rely on differentiated intermediate inputs (see also Ranjan and Lee, 2007; Ferguson and Formai, 2013; Nunn and Trefler, 2014). Manova (2008, 2013) links financial development to the patterns of international trade (see also Chan and Manova, 2015; Manova, Wei, and Zhang, 2015). Building on Romalis (2004), Ciccone and Papaioannou (2009) show that countries with an educated workforce tend to specialize in human capital intensive sectors. The cross-industry cross-country approach has also been used to investigate the effect of product and labor market institutions on comparative advantage, productivity, entrepreneurship, and innovation (e.g., Ciccone and Papaioannou, 2007; Cingano, Leonardi, Messina, and Pica, 2010; Cuñat and Melitz, 2012; Tang, 2012; Griffith and Macartney, 2014). And recent works have employed the cross-industry cross-country approach to study the effects of environmental protection laws and water supply on comparative advantage (Broner, Bustos, and Carvalho, 2015; Debaere, 2015).

Other applications of the cross-industry cross-country approach investigate a variety of different economic issues. For example, the driving forces of outsourcing, foreign direct investment, and the fragmentation of production (e.g., Alfaro and Charlton, 2009; Carluccio and Fally, 2012; Basco, 2013; Blyde and Danielken, 2015; Paunov, 2016). The cross-industry cross-country approach has also been used to examine the economic consequences of cross-country differences in firm size distributions, entry regulation, transaction costs, risk sharing possibilities, skill dispersion, and foreign aid inflows (e.g. Pagano and Schivardi, 2003; Klapper, Laeven, and Rajan, 2006; Acemoglu, Johnson, and Mitton, 2009; Rajan and Subramanian, 2010; Aizenman and Sushko, 2011; Bombardini, Gallipoli, and Pupato, 2012; Michelacci and Schivardi, 2013; Larrain, 2014; Aghion, Howitt, and Prantl, 2014). Recent applications use the cross-industry cross-country setup to assess the effects of financial crises on macroeconomic performance and international trade (e.g. Dell'Ariccia, Detragiache, and Rajan, 2008; Iacovone and Zavacka, 2009; Duchin, Ozbas, and Sensoy, 2010; Claessens, Tong, and Wei, 2012; Laeven and Valencia, 2013) and to examine the effects of fiscal and monetary policy over the business cycle (e.g. Aghion, Farhi, and Kharroubi, 2013; Aghion, Hemous, and Kharroubi, 2014).

Variations of the cross-industry cross-country approach have been employed to examine the economic effects of differences in financial development, institutional quality and trust across regions and over time (e.g. Cetorelli and Strahan, 2006; Bertrand, Schoar, and Tesmar, 2007; Hsieh and Parker, 2007; Aghion, Askenazy, Berman, Cette, and Eymar, 2012; Fafchamps and Schündeln, 2013; Feenstra, Hong, Ma, and Spencer, 2013; Duygan-Bump, Levkov, and Montoriol-Garriga, 2015; Jacobson and von Schedvin, 2015; Cingano and Pinotti, 2016).

2 The Benchmarking Bias

2.1 Empirical Framework

The basis of cross-industry cross-country models are theories linking outcomes for industries in different countries to an interaction between country characteristics and technological industry characteristics. For example, in Rajan and Zingales (1998), the outcome variable is industry growth and the interaction is between country-level financial development and the external-finance dependence of industries. In Nunn (2007), the outcome variable is industry exports and the interaction is between country-level contract enforcement and the intensity with which industries use relationship-specific inputs. As the main theoretical prediction concerns the effect of the interaction between country and industry characteristics, cross-industry cross-country models allow controlling for country and industry fixed effects. An empirical framework that encompasses the models used in the cross-industry cross-country literature is

$$y_{in} = \alpha_n + \alpha_i + \beta x_n z_{in} + v_{in} \tag{1}$$

where y_{in} is the outcome in industry $i = 1,..,I$ and country $n = 1,..,N$; x_n the relevant country characteristic; and z_{in} the relevant industry characteristic. The α_n and α_i denote country and industry fixed effects and v_{in} unobservable determinants of the outcome. The parameter of interest is the coefficient on the industry-country interaction, β. We take v_{in} to be distributed independently of z_{in} and x_n to abstract from omitted variable and reverse causation issues. We also assume that v_{in} has a finite variance and $E(v_{in}|n) = E(v_{in}|i) = 0$, and take x_n to be given with $\sum_{n=1}^{N}(x_n - \overline{x})^2 > 0$ where $\overline{x}$ is the average of x_n.

Estimation of β in (1) would be straightforward if there were data on the technological industry characteristics z_{in} for a broad set of countries. But detailed industry data are unavailable for most countries. Moreover, the cross-industry cross-country literature often focuses on technological industry characteristics that are not directly observable and must therefore be inferred from industry behavior. Such inference is likely to be more reliable in countries where markets are not too distorted. In practice, z_{in} is generally proxied using industry data from a benchmark country, almost always the US.

It is therefore important to understand whether β in (1) can be estimated using industry characteristics from a benchmark country as a proxy for z_{in}. For such a benchmarking estimator to stand a chance, there must be some global element to an industry's technological characteristics. At the same time, it seems unreasonable to presume that industries use the same technology in all countries, as the optimal technology choice depends on many factors that vary across countries (e.g., Bernard and Jones, 1996; Acemoglu and Zilibotti, 2001; Schott, 2004; Caselli, 2005). We therefore model the industry characteristics z_{in} in (1) as the sum of a global industry characteristic (z_i^*) and a country-specific industry characteristic (ε_{in})

$$z_{in} = z_i^* + \varepsilon_{in} \tag{2}$$

where z_i^* is i.i.d. with variance $Var(z^*)$ and independent of other elements of the model.[2] The country-specific industry characteristics ε_{in} allow us to capture that industry characteristics may be more similar for some country-pairs than others in a simple way. We assume $E(\varepsilon_{in}|n) = E(\varepsilon_{in}|i) = 0$; $E(\varepsilon_{in}^2|n) = \sigma^2$; $E(\varepsilon_{in}\varepsilon_{jm}|n, m) = 0$ for all industries $i \neq j$; and the following correlation of idiosyncratic industry characteristics for country pairs $n \neq m$

$$Corr(\varepsilon_{in}\varepsilon_{im}|n, m) = \rho_{mn} \ . \tag{3}$$

Hence, the correlation of industry characteristics z_{in} for country pairs $n \neq m$ is

$$Corr(z_{in}, z_{im}|n, m) = \frac{Var(z^*)}{Var(z^*) + \sigma^2} + \frac{\sigma^2}{Var(z^*) + \sigma^2}\rho_{mn}. \tag{4}$$

$Corr(z_{in}, z_{im}|n, m)$ can be interpreted as an index of technological similarity and country pairs with greater ρ_{mn} are therefore more similar technologically.

2.2 The Bias

As data on the technological industry characteristics z_{in} are unavailable for a broad set of countries, the cross-industry cross-country literature proceeds using a proxy from a benchmark country. We refer to this proxy as z_{iUS} as the benchmark country is almost always the US. Hence, the equation estimated in the cross-industry cross-country literature is

$$y_{in} = a_n + a_i + bx_n z_{iUS} + residual_{in} \tag{5}$$

where a_n and a_i stand for country and industry fixed effects. The main coefficient of interest in the literature is b and the method of estimation is least squares.[3]

To understand the relationship between the least-squares estimator of b in (5) and β in (1), which is the parameter of interest, it is useful to rewrite the least-squares estimator in

[2] While it is reasonable to think of industry characteristics as also reflecting a country-specific component, we can omit such components in (2) without any loss of generality as they can be absorbed into the country fixed effects in (1).

[3] Applications where the exogeneity of x_n is an issue also use instrumental-variables estimation. Our findings carry over to these instances. The easiest way to see this is to think of (5) as the reduced-form equation.

terms of demeaned data (e.g., Baltagi, 2008)

$$(6) \qquad \widehat{b} = \frac{\frac{1}{N}\frac{1}{I}\sum_n \sum_i (z_{iUS} - \overline{z}_{US})(x_n - \overline{x})\left(y_{in} - \overline{y}_n - \overline{y}_i + \overline{y}\right)}{\frac{1}{N}\frac{1}{I}\sum_i \sum_n (z_{iUS} - \overline{z}_{US})^2 (x_n - \overline{x})^2}$$

where $\overline{y}$ is the average of y_{in} across industries and countries; $\overline{y}_i$ the average of y_{in} for industry i; $\overline{y}_n$ the average of y_{in} for country n; $\overline{z}_{US}$ the average of z_{iUS}; and $\overline{x}$ the average of x_n. The probability limit of $\widehat{b}$ is[4]

$$(7) \qquad \widehat{b}^a = \operatorname*{plim}_{I\to\infty} \widehat{b} = \beta\left[1 + \lambda\right].$$

with

$$(8) \qquad \lambda = \frac{\sum_n (x_n - \overline{x})\left[Corr(z_{US}, z_n)x_n\right]}{\sum_n (x_n - \overline{x})^2} - 1$$

where $Corr(z_{US}, z_n) \equiv Corr(z_{iUS}, z_{in}|n)$.

2.2.1 The Case of Attenuation Bias

It follows from (7) that the benchmarking estimator $\widehat{b}$ used in cross-industry cross-country empirics will be attenuated (biased towards zero) if and only if $0 < 1 + \lambda \leq 1$; equivalently using (8)

$$(9) \qquad 0 < \frac{\sum_n (x_n - \overline{x})\left[Corr(z_{US}, z_n)x_n\right]}{\sum_n (x_n - \overline{x})^2} \leq 1.$$

For example, this will be the case if the index of technological similarity with the US is the same for all countries and technological industry characteristics in the US therefore proxy equally well for technological industry characteristics in all other countries, $Corr(z_{US}, z_n) = \pi > 0$. In this case, $\widehat{b}^a = \pi\beta$ where π plays the role of the reliability ratio in the classical measurement error model (e.g. Wooldridge, 2002).

A somewhat more general sufficient condition for $\widehat{b}$ to be biased towards zero is that the index of technological similarity with the US, $Corr(z_{US}, z_n)$, is decreasing in the country characteristic x_n, but that $Corr(z_{US}, z_n)x_n$ is increasing in x_n (if the latter condition is not satisfied, the benchmarking estimator may have the wrong sign).

[4] Substituting (1) into (6) and taking the probability limit as $I \to \infty$ of the numerator yields $\operatorname*{plim}_{I\to\infty} \beta\left(\frac{1}{N}\sum_n\left((x_n - \overline{x})x_n \frac{1}{I}\sum_i (\varepsilon_{in} - \varepsilon_{iUS})\varepsilon_{iUS}\right)\right) + \operatorname*{plim}_{I\to\infty} \beta\left(\frac{1}{N}\frac{1}{I}\sum_i\sum_n (z_{iUS} - \overline{z}_{US})^2 (x_n - \overline{x})^2\right)$. Using (3) this simplifies to $\beta\left(\frac{1}{N}\sum_n (x_n - \overline{x})x_n(\rho_{USn} - 1)\sigma^2\right) + \beta Var(z_{US})\left(\frac{1}{N}\sum_n (x_n - \overline{x})^2\right)$. The probability limit of the denominator when substituting (1) into (6) is $Var(z_{US})\left(\frac{1}{N}\sum_n (x_n - \overline{x})^2\right)$. Hence, the probability limit of (6) is $\beta + \beta\left(\frac{1}{N}\sum_n (x_n - \overline{x})x_n(\rho_{USn} - 1)\sigma^2\right) / \left(Var(z_{US})\left(\frac{1}{N}\sum_n (x_n - \overline{x})^2\right)\right)$ which defining $Corr(z_{US}, z_n) \equiv Corr(z_{iUS}, z_{in}|n)$ and making use of (4) and $Var(z_{US}) = Var(z^*) + \sigma^2$ can be written as in (7) and (8).

2.2.2 The Case of Amplification Bias

But the benchmarking estimator $\widehat{b}$ can yield estimates of β that are biased away from zero (amplified). From (7) and (8) it follows that this will be the case if and only if $\lambda > 0$ or equivalently

$$\text{(10)} \qquad \frac{\sum_n (x_n - \overline{x}) \left[Corr(z_{US}, z_n) x_n \right]}{\sum_n (x_n - \overline{x})^2} > 1.$$

The left-hand side of the inequality in (10) turns out to be the standard formula for the least-squares slope of a regression of $Corr(z_{US}, z_n)x_n$ on x_n. Hence, the condition for an amplification bias in (10) is equivalent to a least-squares slope greater unity when regressing $Corr(z_{US}, z_n)x_n$ on x_n. For this to be the case, the index of technological similarity of country n with the US, $Corr(z_{US}, z_n)$, must be strictly increasing in the country characteristic x_n over some range.

To develop some intuition for the amplification bias, it is useful to rewrite the model in (1) in terms of two equations

$$\text{(11)} \qquad y_{in} = \alpha_n + \alpha_i + \gamma_n z_{in} + v_{in}$$

where

$$\text{(12)} \qquad \gamma_n = \beta x_n.$$

The country-specific slope parameters γ_n capture cross-country differences in how industry outcomes covary with industry characteristics. For example, in Rajan and Zingales (1998) these slope parameters would capture cross-country differences in the covariation between industry growth and the external-finance dependence of industries. In Nunn (2007), the slope parameters would capture cross-country differences in the covariation between industry exports and the relationship-specific input intensity of industries.

Now imagine estimating the country-specific slopes γ_n in (11) with least squares using US industry characteristics z_{iUS} as a proxy of industry characteristics z_{in}. The resulting least-squares slopes $\widehat{\gamma}_n$ reflect the covariation between industry outcomes in country n and US industry characteristics z_{iUS}. Substituting the least-squares slopes $\widehat{\gamma}_n$ in (6) yields that the benchmarking estimator can be expressed as the least-squares slope of a regression of the country-specific slope estimates $\widehat{\gamma}_n$ on the country characteristics x_n

$$\text{(13)} \qquad \widehat{b} = \frac{\sum_n \widehat{\gamma}_n (x_n - \overline{x})}{\sum_n (x_n - \overline{x})^2}.$$ [5]

[5] To see this, note that the least-squares estimates of the country-specific slopes expressed in terms of

Similarly, the probability limit of the benchmarking estimator $\widehat{b}^a$ can be written as the least-squares slope when regressing $\widehat{\gamma}_n^a$ on x_n

$$\widehat{b}^a = \frac{\sum_n \widehat{\gamma}_n^a (x_n - \overline{x})}{\sum_n (x_n - \overline{x})^2} \tag{14}$$

where

$$\widehat{\gamma}_n^a = \gamma_n Corr(z_{US}, z_n). \tag{15}$$

Equation (14) shows that the bias of the benchmarking estimator will reflect how the bias of the country-specific least-squares slopes covaries with the country characteristic x_n. As a result, the amplification bias can arise even if all country-specific slope estimates are attenuated because of classical measurement error, as long as the attenuation bias is weaker for countries with greater x_n.

A setting where countries fall into two groups The amplification bias emerges most clearly in a setting where countries except the US fall into two groups, A and B, and countries in the same group are identical. In this two-group setting, (13) simplifies to

$$\widehat{b} = \frac{\widehat{\gamma}_A - \widehat{\gamma}_B}{x_A - x_B}. \tag{16}$$

That is, the benchmarking estimator is simply the slope of the line connecting the two points $(x_A, \widehat{\gamma}_A)$ and $(x_B, \widehat{\gamma}_B)$. Making use of (15), the probability limit of (16) is

$$\widehat{b}^a = \frac{\widehat{\gamma}_A^a - \widehat{\gamma}_B^a}{x_A - x_B} = \beta \left(\frac{Corr(z_{US}, z_A) x_A - Corr(z_{US}, z_B) x_B}{x_A - x_B} \right) \tag{17}$$

where $Corr(z_{US}, z_A) \equiv Corr(z_{iUS}, z_{in}|n)$ for all countries n in group A and $Corr(z_{US}, z_B)$ is defined analogously. There is an amplification bias if and only if the term in parenthesis is greater than unity. The simplest way to see that the amplification bias can be very large is to consider the case where where (i) countries in group A have the same technological characteristics as the US and US industry characteristics therefore proxy perfectly for industry characteristics of these countries, $Corr(z_{US}, z_A) = 1$, but (ii) countries in group B have technological characteristics that differ from the US to the point where US industry characteristics are uncorrelated with industry characteristics of these countries, $Corr(z_{US}, z_B) = 0$. In this case, (17) simplifies to

$$\widehat{b}^a = \beta \left(\frac{x_A}{x_A - x_B} \right). \tag{18}$$

demeaned data (e.g., Baltagi, 2008) are $\widehat{\gamma}_n = \sum_i z_{iUS} \left(y_{in} - \overline{y}_n - \overline{y}_i + \overline{y} \right) \Big/ \sum_i z_{iUS}^2$.

Hence, there will be an amplification bias if $x_A > x_B > 0$ and the bias will be very large if the two groups of countries have very similar characteristics x. This is because in this case there is a strong positive association between the country characteristic x_n and technological similarity with the US.

Figure 1 illustrates the true model and the estimated model in the two-group setting for $\beta > 0$. In figure 1A, we graph the true country-specific slopes γ_A and γ_B against x_A and x_B. As $\gamma_n = \beta x_n$, the true parameter of interest β is simply the slope of the line connecting the two points (x_A, γ_A) and (x_B, γ_B). In figure 1B, we also graph the probability limits of the country-specific slope estimates $\widehat{\gamma}_A^a$ and $\widehat{\gamma}_B^a$ against x_A and x_B. Equation (17) implies that the probability limit of the benchmarking estimator $\widehat{b}^a$ is simply the slope of the line connecting the two points $(x_A, \widehat{\gamma}_A^a)$ and $(x_B, \widehat{\gamma}_B^a)$. The amplification bias $\widehat{b}^a > \beta > 0$ follows because US industry characteristics are a perfect proxy for industry characteristics of countries in group A, which implies $\widehat{\gamma}_A^a = \gamma_A$, but do not proxy for industry characteristics of countries in group B, which implies $\widehat{\gamma}_B^a = 0 < \gamma_B$. More generally, the amplification bias of the benchmarking estimator arises when the attenuation bias of the country-specific slope estimates (which reflects technological dissimilarity with the US) is sufficiently stronger for countries that are less similar to the US in the country characteristic x.

Figure 1A: True Model

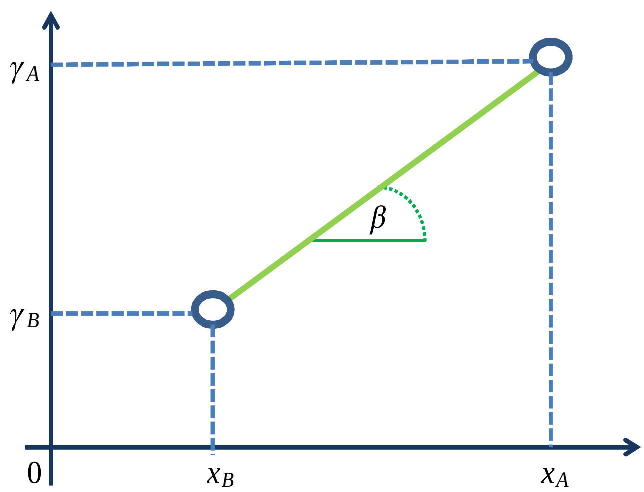
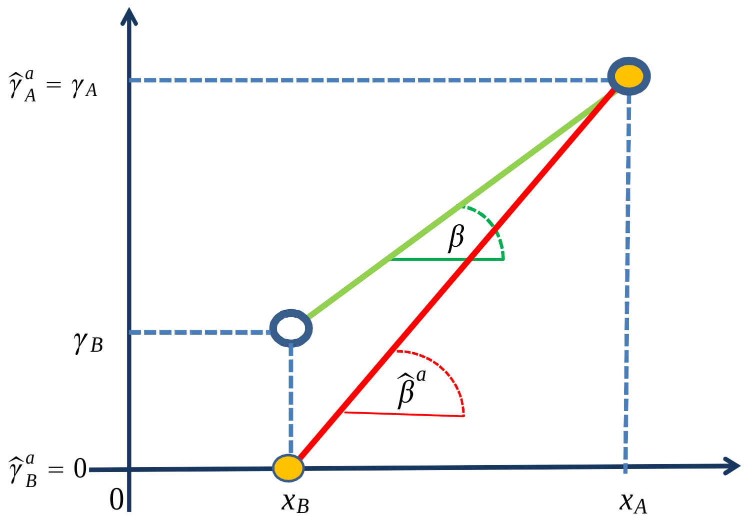


Figure 1B: Amplification Bias



Notes: True country-specific slopes (bold circles) and estimated country-specific slopes (filled circles) in the two-group model where the benchmarking estimator is biased away from zero (amplification bias). There is amplification bias although the country-specific slope estimates are weakly biased towards zero (attenuated).

3 Estimating Comparative Advantage Models with a Benchmarking Estimator

The (standard) benchmarking estimator of the empirical cross-industry cross-country literature has been used widely to investigate the determinants of comparative advantage in international trade (e.g. Romalis, 2004; Levchenko, 2007; Nunn, 2007; Manova, 2008, 2013; Cuñat and Melitz, 2012). In this context, there turns out to be a new benchmarking estimator that yields a lower bound on the strength of comparative advantage under the assumption that at least one pair of countries differs in the direction of comparative advantage. We first illustrate the argument in a model of comparative advantage where all countries except the US fall into two groups and countries in the same group are identical. A special feature of this setting is that the new benchmarking estimator turns out to be identical to the (standard) benchmarking estimator used in the literature. Then we discuss the new benchmarking estimator in a more general setting (where the new benchmarking estimator is no longer identical to the benchmarking estimator used in the cross-industry cross-country literature).

3.1 Model and Assumptions

It is useful to rewrite (without loss of generality) the country characteristic x_n in (11) and (12) as $x_n = q_n - q^*$. This yields

(19) $$y_{in} = \alpha_n + \alpha_i + \gamma_n z_{in} + v_{in}$$

(20) $$\gamma_n = \beta(q_n - q^*).$$

q_n is the country characteristic that may determine a country's comparative advantage and q^* the value of q_n where comparative advantage switches from high-z industries to low-z industries as long as $\beta \neq 0$. We can obtain a lower bound on the strength of comparative advantage β under two assumptions. The first assumption, which is standard in the comparative advantage literature using the cross-industry cross-country approach, is that high-z industries in the US also tend to be high-z industries elsewhere. The second assumption – which will turn out to be testable – is that there is at least one country on either side of the threshold q^*. Formally:

(A1) High-z industries in the US tend to be high-z industries elsewhere, $Corr(z_{US}, z_n) > 0$.

(A2) There is at least one country on either side of the threshold q^*, that is $(q_n - q^*)(q_m - q^*) < 0$ for at least one pair of countries n, m. Or equivalently, as long as $\beta \neq 0$, at least one country has a comparative advantage in high-z industries and at least one country has a comparative advantage in low-z industries.

A setting where countries fall into two groups To illustrate why these two assumptions allow for a benchmarking estimator that yields a lower bound on the true strength of comparative advantage, we return to the setting where countries except the US fall into two groups and countries in the same group are identical. A special feature of this setting is that the new benchmarking estimator turns out to be identical to the (standard) benchmarking estimator used in the literature. We can therefore illustrate the argument using the standard benchmarking estimator and postpone the introduction of the new benchmarking estimator.

As shown above, in the setting where countries except the US fall into two groups and countries in the same group are identical, the key formulas for the (standard) benchmarking estimator $\widehat{b}$ used in the cross-industry cross-country literature simplify to (16) and (17). Substituting $x_n = q_n - q^*$ yields

(21) $$\widehat{b} = \frac{\widehat{\gamma}_A - \widehat{\gamma}_B}{q_A - q_B}$$

and

$$\widehat{b}^a = \frac{\widehat{\gamma}_A^a - \widehat{\gamma}_B^a}{q_A - q_B} = \beta \left(\frac{Corr(z_{US}, z_A)(q_A - q^*) - Corr(z_{US}, z_B)(q_B - q^*)}{q_A - q_B} \right). \tag{22}$$

The benchmarking estimator $\widehat{b}$ will be attenuated and therefore yield a lower bound on the true effect β, if and only if the term in parenthesis on the right-hand side of (22) is strictly greater than zero but smaller than unity. This is equivalent to[6]

$$\begin{aligned} & [Corr(z_{US}, z_B) + Corr(z_{US}, z_A)]\,(q_A - q^*)(q_B - q^*) \\ < \;& Corr(z_{US}, z_A)(q_A - q^*)^2 + Corr(z_{US}, z_B)(q_B - q^*)^2 \end{aligned} \tag{23}$$

and

$$\begin{aligned} & [2 - Corr(z_{US}, z_A) - Corr(z_{US}, z_B)](q_A - q^*)(q_B - q^*) \\ \leq \;& [1 - Corr(z_{US}, z_B)]\,(q_B - q^*)^2 + [1 - Corr(z_{US}, z_A)]\,(q_A - q^*)^2. \end{aligned} \tag{24}$$

Both conditions will be satisfied if assumptions (A1) and (A2) hold. To see this, notice that because countries in the same group are identical, assumption (A2) is equivalent to $(q_A - q^*)(q_B - q^*) < 0$. Combined with assumption (A1), this implies that the left-hand side of (23) is strictly negative while the right-hand side is positive. Assumptions (A1) and (A2) also imply that the left-hand side of (24) is negative while the right-hand side is positive. Hence, assumptions (A1) and (A2) imply that the term in parenthesis on the right-hand-side of (22) is strictly greater than zero but smaller than unity and that the benchmarking estimator $\widehat{b}$ will be biased towards zero. When US industry characteristics are an imperfect proxy for industry characteristics of countries in group A or group B, the inequality in (24) will be strict and the benchmarking estimator $\widehat{b}$ will be strictly biased towards zero.

Figure 2 illustrates the true model and the estimated model for $\beta > 0$. In figure 2A, we graph the true country-specific slopes γ_A and γ_B against $q_A - q^* > 0$ and $q_B - q^* < 0$. As $\gamma_n = \beta(q_n - q^*)$, the true parameter of interest β is simply the slope of the line connecting the two points. In figure 2B, we also graph the probability limits of the country-specific slope estimates $\widehat{\gamma}_A^a$ and $\widehat{\gamma}_B^a$ against $q_A - q^*$ and $q_B - q^*$. According to (22), the slope of the line connecting these two new points yields the probability limit of the benchmarking estimator $\widehat{b}^a$. As $\widehat{\gamma}_A^a > 0$ and $\widehat{\gamma}_B^a < 0$ are biased towards zero, it follows that the line connecting the country-specific slope estimates must be less steep than the line connecting the true country-specific slopes. Hence, $\widehat{b}^a$ is biased towards zero (attenuated). For $\beta < 0$ the argument is analogous.

[6] To derive the conditions in (23) and (24), it is convenient to write the term in parenthesis in (22) as θ_1/θ_2. As long as $q_A \neq q_B$, the condition $0 < \theta_1/\theta_2 \leq 1$ is equivalent to $\theta_1\theta_2 > 0$, which is the condition in (23), and $(\theta_1/\theta_2)(q_A - q_B)^2 \leq (q_A - q_B)^2$, which making use of $q_A - q_B = (q_A - q^*) - (q_B - q^*)$ is the condition in (24).

Figure 2A: True Model

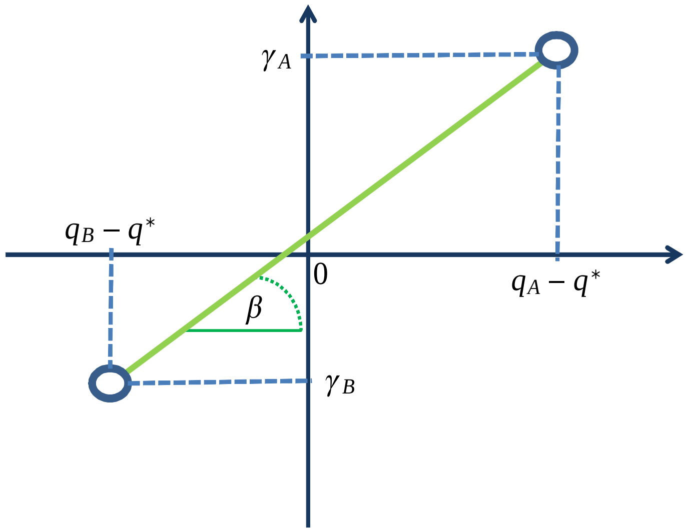
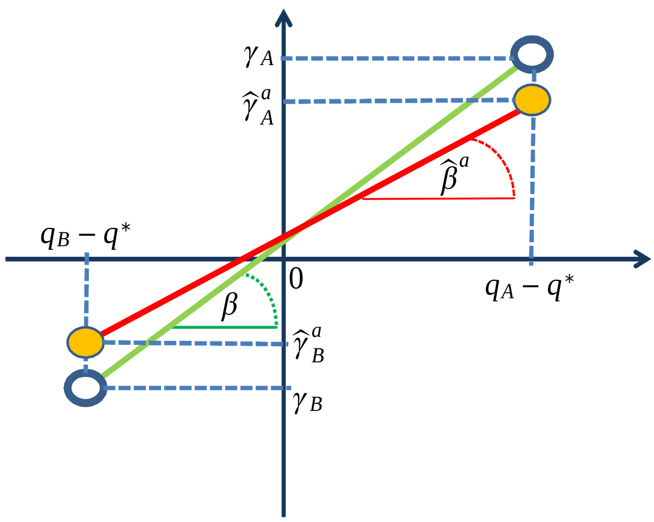


Figure 2B: Estimated Model



Notes: True country-specific slopes (bold circles) and estimated country-specific slopes (filled circles) in the two-group model of comparative advantage where the benchmarking estimator of the cross-industry cross-country approach is necessarily biased towards zero (attenuation bias).

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To better understand this result, it is useful to compare figure $2B$ where the benchmarking estimator $\widehat{b}$ is biased towards zero, with figure $1B$ where $\widehat{b}$ is biased away from zero. In both figures, all country-specific slope estimates are biased towards zero. But in figure $1B$ this results in the benchmarking estimator $\widehat{b}$ being biased away from zero, while in figure $2B$ $\widehat{b}$ is biased towards zero. From the figures it becomes clear that this is because in figure $2B$, there are countries on both sides of q^* and these countries differ in the direction of their comparative advantage. As a result, the line connecting the country-specific slope estimates in figure $2B$ is a clockwise rotation of the line connecting the true country-specific slopes. Hence, $\widehat{b}^a$ is necessarily biased towards zero.

3.2 A New Benchmarking Estimator

There continues to be a benchmarking estimator yielding a lower bound on the true strength of comparative advantage associated with country characteristic q_n in (19) and (20) when there are many different countries (but this estimator is no longer the benchmarking estimator used in the cross-industry cross-country literature). To show this, we start with the case where it is known which countries are on the same side of q^*. Or equivalently as long as $\beta \neq 0$, the case where it is known which countries have a comparative advantage going in the same direction. Then we turn to the case where the grouping of countries by the direction of their comparative advantage is unknown.

3.2.1 Known Country Grouping

If it were known which countries are on the same side of q^*, we could put countries on one side of q^* into group A and countries on the other side of q^* into group B. Then we could estimate the strength of comparative advantage associated with country characteristic q_n using the following new benchmarking estimator

$$(25) \qquad \widehat{b}_G = \frac{\overline{\overline{\gamma}}_{nA} - \overline{\overline{\gamma}}_{nB}}{\overline{q}_A - \overline{q}_B}$$

where $\overline{\overline{\gamma}}_A$ and $\overline{\overline{\gamma}}_B$ denote the average country-specific slope estimate for countries in group A and group B; $\overline{q}_A$ and $\overline{q}_B$ are the average country characteristic in groups A and B (it does not matter which group countries with q_n at the threshold q^* are assigned to; we denote the new benchmarking estimator with a subscript G because the estimator can be seen as a grouped-data estimator).[7] It is immediate that the new benchmarking estimator in (25) is identical to the standard benchmarking estimator in (21) when countries in the same group are identical. Hence, the argument in section 3.1 that the standard benchmarking estimator is biased towards zero under assumptions (A1) and (A2) when countries in the same group are identical, implies that the new benchmarking estimator is also biased towards zero in this

[7] See Angrist (1991) for an application and a brief historical review of grouped-data estimation.

special case. In the general case where the strength of comparative advantage differs among countries with the same direction of comparative advantage, (i) the new benchmarking estimator and the standard benchmarking estimator are no longer identical, and (ii) the standard benchmarking estimator may be biased upward or downward even if assumptions (A1) and (A2) hold. However, assumptions (A1) and (A2) imply that the new benchmarking estimator in (25) is biased towards zero this general case also, and the new benchmarking estimator therefore continues to yield a lower bound on the strength of the true effect. To see this, we first obtain the probability limit of (25) using (15), which yields

$$\widehat{b}_G^a = \frac{\overline{\widehat{\gamma}_{nA}^a} - \overline{\widehat{\gamma}_{mB}^a}}{\overline{q}_A - \overline{q}_B} = \beta \left(\frac{\overline{Corr(z_{US}, z_{nA})(q_{nA} - q^*)} - \overline{Corr(z_{US}, z_{mB})(q_{mB} - q^*)}}{\overline{q}_A - \overline{q}_B} \right) \tag{26}$$

where $\overline{Corr(z_{US}, z_{nA})(q_{nA} - q^*)}$ is the average of $Corr(z_{US}, z_{nA})(q_{nA} - q^*)$ across countries n in group A and $\overline{Corr(z_{US}, z_{mB})(q_{mB} - q^*)}$ is defined analogously for countries m in group B. (26) implies that the new benchmarking estimator will be attenuated and therefore yield a lower bound on the true effect, if and only if the term in parenthesis is strictly greater than zero but smaller than unity. This turns out to be equivalent to[8]

$$\begin{aligned} & \overline{Corr(z_{US}, z_{nA})(q_{nA} - q^*)\,(\overline{q}_B - q^*)} + \overline{Corr(z_{US}, z_{mB})(q_{mB} - q^*)\,(\overline{q}_A - q^*)} \\ < \; & \overline{Corr(z_{US}, z_{nA})(q_{nA} - q^*)\,(\overline{q}_A - q^*)} + \overline{Corr(z_{US}, z_{mB})(q_{mB} - q^*)\,(\overline{q}_B - q^*)} \end{aligned} \tag{27}$$

and

$$\begin{aligned} & \overline{[1 - Corr(z_{US}, z_{nA})](q_{nA} - q^*)\,(\overline{q}_B - q^*)} + \overline{[1 - Corr(z_{US}, z_{mB})](q_{mB} - q^*)\,(\overline{q}_A - q^*)} \\ \leq \; & \overline{[1 - Corr(z_{US}, z_{nA})]\,(q_{nA} - q^*)\,(\overline{q}_A - q^*)} + \overline{[1 - Corr(z_{US}, z_{mB})]\,(q_{mB} - q^*)\,(\overline{q}_B - q^*)}. \end{aligned} \tag{28}$$

Both conditions will be satisfied if assumptions (A1) and (A2) hold. To see this, notice that the left-hand side of (27) is strictly negative as $Corr(z_{US}, z_{nA}) > 0$, $Corr(z_{US}, z_{mB}) > 0$, and at least one pair of countries differs in the direction of their comparative advantage, $(q_{nA} - q^*)(q_{mB} - q^*) < 0$; and the right-hand side of (27) is positive as countries in the same group have the same direction of comparative advantage, $(q_{nA} - q^*)\,(\overline{q}_A - q^*) \geq 0$ and $(q_{mB} - q^*)\,(\overline{q}_B - q^*) \geq 0$. A similar argument yields that the left-hand side of (28) is negative while the right-hand side is positive. Hence, the term in parenthesis in (26) is strictly greater than zero but smaller than unity and the grouping estimator $\widehat{b}_G$ is biased towards zero. When US industry characteristics are an imperfect proxy for industry characteristics in at least one country where $q_n \neq q^*$, the inequality in (28) will be strict and the new benchmarking estimator $\widehat{b}_G$ will be strictly biased towards zero.

[8]The argument is analogous to that in footnote 6.

Figure 3 illustrates the true model and the estimated model for $\beta > 0$. In figure $3A$, we graph the true country-specific slopes γ_n against $q_n - q^*$ with each circle representing a country. As $\gamma_n = \beta(q_n - q^*)$, the true parameter of interest β is the slope of the line through the circles. In figure $3B$, we also graph the probability limits of the country-specific slope estimates $\widehat{\gamma}_n^a$ against $q_n - q^*$. All country-specific slope estimates are biased towards zero. This means that we underestimate the country-specific slopes for countries with comparative advantage in high-z industries and we overestimate the country-specific slopes for countries with comparative advantage in low-z industries. As a result, the new benchmarking estimator $\widehat{b}_G$ – which according to (26) is the slope of the line connecting the average country-specific slope estimate for countries with comparative advantage in high-z industries with the average country-specific slope estimate for countries with comparative advantage in low-z industries – will necessarily be biased towards zero.

Figure 3A: True Model

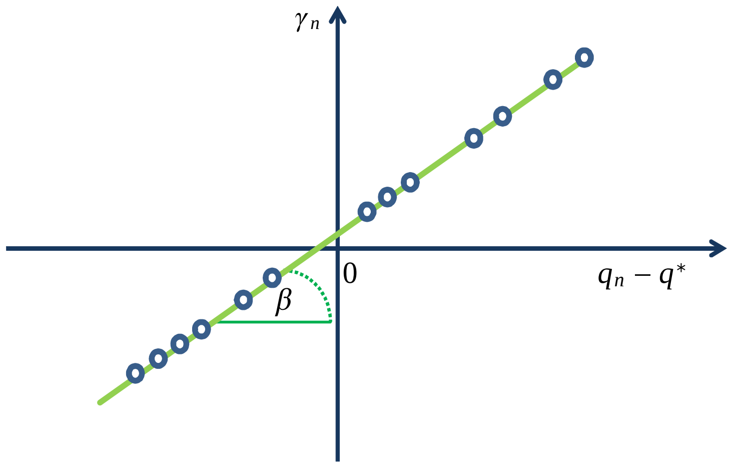
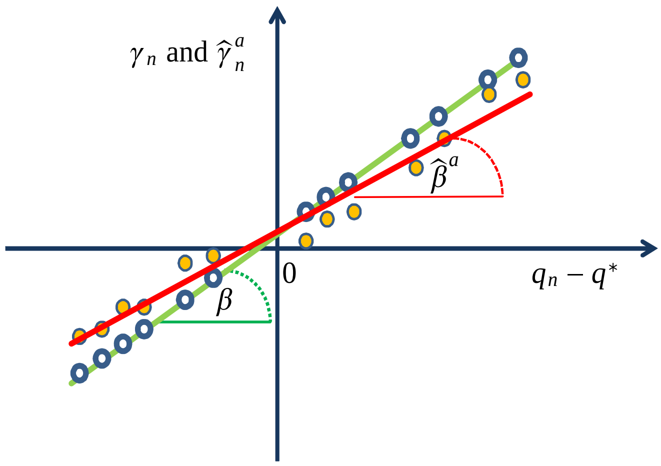


Figure 3B: Estimated Model



Notes: True country-specific slopes (bold circles) and estimated country-specific slopes (filled circles) in a model of comparative advantage with many different countries (each circle represents a country). In this case the new benchmarking estimator is necessarily biased towards zero (attenuation bias).

Summarizing, the new benchmarking estimator is downward biased in figure 3 – and hence a lower bound on the true effect – because (A1) and (A2) combined with (25) imply

(29)
$$\frac{\overbrace{\widehat{\overline{\overline{\gamma}}}_{nA}}^{\downarrow bias} - \overbrace{\widehat{\overline{\overline{\gamma}}}_{nB}}^{\uparrow bias}}{\overline{q}_A - \overline{q}_B} \quad \Rightarrow \quad \overbrace{\widehat{b}_G}^{\downarrow bias}.$$

For $\beta < 0$, the argument is analogous.

A 2SLS Interpretation The new benchmarking estimator in (25) turns out to have an interpretation as a 2SLS estimator applied to the cross-industry cross-country model

(30)
$$y_{in} = \alpha_n + \alpha_i + b z_{iUS} q_n + residual_{in}.$$

To see this, define an indicator function 1_n^* that assigns a value of 1 to countries in group A and a value of 0 to all other countries (or the other way round). Now we can estimate (30) using 2SLS with the product of the indicator function and the US industry characteristics $z_{iUS} 1_n^*$ as an instrument for the interaction term $z_{iUS} q_n$. This 2SLS estimator can be expressed in terms of demeaned data as

(31)
$$\widehat{b}_{G,2SLS} = \frac{\sum_n \widehat{\gamma}_n \left(1_n^* - \overline{1}^*\right)}{\sum_n q_n \left(1_n^* - \overline{1}^*\right)}$$

where the $\widehat{\gamma}_n$ are the country-specific least-squares slopes estimated using US industry characteristics as a proxy for industry characteristics in all other countries and $\overline{1}^* = \frac{1}{N}\sum_n 1_n^*$. It is now straightforward to show that the right-hand side of (31) is the same as the right-hand side of (25) and hence $\widehat{b}_{G,2SLS} = \widehat{b}_G$.

3.2.2 Estimated Country Grouping

The 2SLS estimator in (31) cannot be implemented directly because we generally do not know whether countries have a comparative advantage in high-z or low-z industries. As a result, we cannot generate the necessary indicator function 1_n^*. But it turns out that we can estimate 1_n^* consistently under the (testable) assumption $\beta \neq 0$. As shown in Wooldridge (2002, Section 6.1.2), the 2SLS estimator using a consistently estimated instrument is not only consistent but has the same asymptotic distribution as the 2SLS estimator using the actual instrument under weak conditions. Hence, we can obtain an estimate with the same asymptotic distribution as $\widehat{b}_{G,2SLS}$ by estimating the cross-industry cross-country model in (30) with 2SLS and instrumenting $z_{iUS}q_n$ with $z_{iUS}\widehat{1}_n^*$ where $\widehat{1}_n^*$ is a consistent estimator of 1_n^*. We now discuss two approaches to obtain such a consistent estimator. A simple approach that only relies on the sign of the country-specific slope estimates and a second, somewhat more complex, approach that also considers the country characteristic shaping the direction of comparative advantage.

Simple Approach The first estimator, which we refer to as $\widehat{1}_{1n}^*$, is an indicator that takes the value of 1 for countries n with $\widehat{\gamma}_n \geq 0$ and the value of 0 for all other countries. Recall that $\widehat{\gamma}_n$ converges to $\widehat{\gamma}_n^a = \gamma_n Corr(z_{US}, z_n) = \beta(q_n - q^*)Corr(z_{US}, z_n)$, where we made use of (15) and (20). Hence, as long as $\beta \neq 0$, assumption (A1) implies that $\widehat{\gamma}_n^a$ has the same sign for countries on the same side of q^* and $\widehat{1}_{1n}^*$ is a consistent estimator of 1_n^* . The hypothesis $\beta = 0$ can be tested, as it implies that $\gamma_n = 0$ for all countries n. We can therefore proceed in three steps. First, estimate the least-squares slopes $\widehat{\gamma}_n$ and test the hypothesis $\gamma_n = 0$ for all n. Second, if this hypothesis can be rejected, obtain the estimate of the indicator function for each country $\widehat{1}_{1n}^*$. Third, estimate the model in (30) with 2SLS using $z_{iUS}\widehat{1}_{1n}^*$ as an instrument for $z_{iUS}q_n$.

Alternative Approach There is a second, somewhat more complex, approach to obtain a consistent estimator of the indicator function 1_n^*. This approach differs from the first approach in that it also uses information on the characteristics q_n that may be driving countries' comparative advantage. To see the basic idea, suppose that $\beta > 0$ and that (20) holds. In this case, countries with $q_n \geq q^*$ have a comparative advantage in high-z industries and countries with $q_n < q^*$ have a comparative advantage in low-z industries. The idea of the approach is to estimate q^* and then group countries according to whether q_n is above or below q^*. Estimating q^* would be simple if we observed γ_n. We could chose a value $\widehat{q}^*$ that maximizes the share of countries with $q_n \geq \widehat{q}^*$ and $\gamma_n \geq 0$ plus the share of countries with $q_n < \widehat{q}^*$ and $\gamma_n < 0$. This can be thought of estimating q^* so as to maximize the share of countries whose direction of comparative advantage conforms to (20). Once we have obtained the threshold $\widehat{q}^*$ we could generate the indicator function 1_n^* by assigning a value of 1 to countries n with $q_n \geq \widehat{q}^*$ and a value of 0 to all other countries. This approach would yield a unique indicator function, although the threshold $\widehat{q}^*$ would not be unique, as the data for the country characteristic q_n are discrete. If one wants to ensure a unique threshold also, this can be easily done by choosing $\widehat{q}^*$ from the set of values taken by the country characteristic q_n. An analogous approach can be used to obtain $\widehat{q}^*$ when $\beta < 0$. If we observed γ_n, we could chose a threshold $\widehat{q}^*$ from the set of values taken by the country characteristic q_n that maximizes the share of countries with $q_n \geq \widehat{q}^*$ and $\gamma_n \leq 0$ plus the share of countries with $q_n < \widehat{q}^*$ and $\gamma_n > 0$. This can again be thought of as estimating q^* to maximize the share of countries whose direction of comparative advantage conforms to (20).

In practice, we generally neither observe the γ_n nor do we know whether $\beta > 0$ or $\beta < 0$. But instead of the γ_n we can use the least-squares estimates $\widehat{\gamma}_n$, as their sign is a consistent estimate of the direction of countries' comparative advantage under assumption (A1). That we do not observe whether $\beta > 0$ or $\beta < 0$ can be taken care of by choosing either the threshold estimated under the assumption $\beta > 0$ or the threshold estimated under the assumption $\beta < 0$, depending on which yields a greater share of countries whose direction of comparative advantage conforms to (20). Summarizing, the alternative approach generates a consistent estimate of the indicator function 1_n^* by splitting countries into two groups based on an estimate of the threshold q^*. This estimate is obtained by maximizing the share of countries whose estimated direction of comparative advantage conforms to (20).

To explain the second approach more formally, we need to introduce a considerable amount of notation. Let Q be the set that collects the values of q_n for all countries n. Define $p(q|\, q \in Q)$ as the share of countries with $q_n \geq q$ and a comparative advantage in high-z industries plus the share of countries with $q_n < q$ and a strict comparative advantage in low-z industries,

$$p(q|\, q \in Q) = \text{share of countries with } \begin{cases} q_n < q \text{ and } \gamma_n < 0 \\ q_n \geq q \text{ and } \gamma_n \geq 0 \end{cases} . \tag{32}$$

Also define $m(q|\, q \in Q)$ as the share of countries with $q_n \geq q$ and a comparative advantage in low-z industries plus the share countries with $q_n < q$ and a strict comparative advantage in high-z industries

$$(33) \qquad s(q|\, q \in Q) = \text{share of countries with} \begin{cases} q_n < q \text{ and } \gamma_n > 0 \\ q_n \geq q \text{ and } \gamma_n \leq 0 \end{cases}.$$

Let q_Q^* be the value $q \in Q$ such that countries with $q_n \geq q_Q^*$ have a comparative advantage going in the same direction and countries with $q_n < q_Q^*$ also have a comparative advantage going in the same direction. If $\beta > 0$, q_Q^* is straightforward to determine as it is the unique value maximizing $p(q|\, q \in Q)$. Similarly, q_Q^* is also straightforward to determined if $\beta < 0$, as it is the unique value maximizing $s(q|\, q \in Q)$. Collecting the cases $\beta > 0$ and $\beta < 0$ it follows that as long as $\beta \neq 0$, we can determine q_Q^* as

$$(34) \qquad q_Q^* = \begin{cases} \text{argmax } p(q|\, q \in Q) \text{ if } \max p(q|\, q \in Q) \geq \max s(q|\, q \in Q) \\ \text{argmax } s(q|\, q \in Q) \text{ if } \max s(q|\, q \in Q) > \max p(q|\, q \in Q) \end{cases}.$$

To see this, notice that if $\beta > 0$, max $p(q|\, q \in Q) = 1$ while max $s(q|\, q \in Q) = 0$ except if there are countries that happen to have a value of q_n exactly equal to q^*; in this case, max $s(q|\, q \in Q) = M/N$ with N the number of countries and M the number of countries with $q_n = q^*$. On the other hand, if $\beta < 0$, max $s(q|\, q \in Q) = 1$ while max $p(q|\, q \in Q) = 0$ except if there are countries that happen to have a value of q_n exactly equal to q^*; in this case, max $p(q|\, q \in Q) = M/N$.

Using (34), we can obtain a consistent estimator of q_Q^* once we have consistent estimators of $p(q)$ and $s(q)$. Moreover, consistent estimators of $p(q)$ and $s(q)$ are straightforward to find under assumption (A1). In this case, $\widehat{\gamma}_n^a \geq 0$ if and only if $\gamma_n \geq 0$, see (15). Hence, we can obtain consistent estimators $\widehat{p}(q)$ and $\widehat{s}(q)$ of $p(q)$ and $s(q)$ by replacing γ_n by $\widehat{\gamma}_n$ in (32) and (33). Then we can replace $p(q)$ and $s(q)$ by $\widehat{p}(q)$ and $\widehat{s}(q)$ in (34) to obtain a consistent estimator $\widehat{q}_Q^*$ of q_Q^*. Finally, we can obtain our alternative consistent estimator of 1_n^* as the indicator function $\widehat{1}_{2n}^*$ that assigns a value of 1 to all countries n with $q_n \geq \widehat{q}_Q^*$ and the value of 0 to all other countries (or the other way around).

3.2.3 Applying the 2SLS Grouping Estimator

We now illustrate the alternative benchmarking estimator in the context of Nunn's (2007) empirical analysis of the effect of contract enforcement on comparative advantage in industries that depend more on relationship-specific intermediate inputs (see also Levchenko, 2007, and Costinot, 2009, for related empirical and theoretical findings). Nunn's analysis is based on the cross-industry cross-country model

$$(35) \qquad \ln e_{in} = a_n + a_i + b z_{iUS} q_n + residual_{in}$$

where $\ln e_{in}$ is the log value of exports of country n in industry i; q_n the quality of contract enforcement in country n; and z_{iUS} a measure of industry i's dependence on relationship-specific intermediate inputs obtained using US data. Nunn's key finding is that b is positive and statistically significant, indicating that countries with better contract enforcement export relatively more in industries that depend more on relationship-specific intermediate inputs.

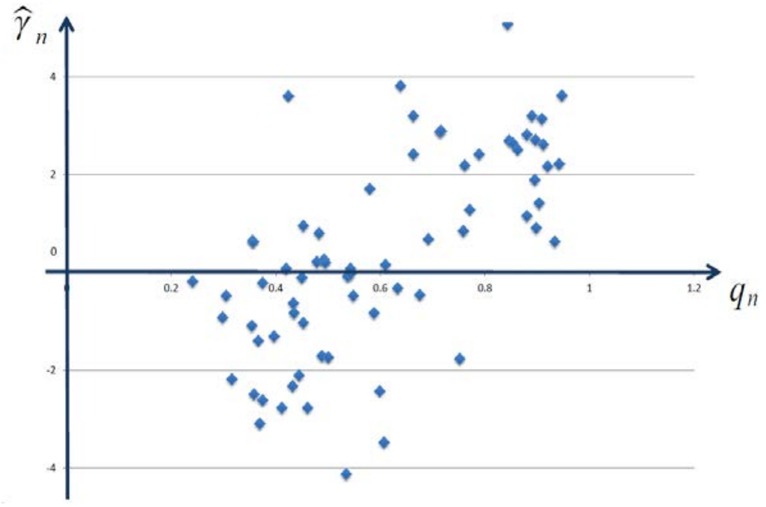
To apply our 2SLS benchmarking estimator, we first need to estimate the country-specific slopes $\gamma_n = bq_n$ in

$$\ln e_{in} = \alpha_n + \alpha_i + \gamma_n z_{iUS} + residual_{in}. \tag{36}$$

The least-squares slope estimates $\widehat{\gamma}_n$ tell us how much more country n exports in industries that depend more on relationship-specific intermediate inputs. We plot these estimates against the quality of contract enforcement q_n in figure 4. The second step is to use the least-squares slope estimates $\widehat{\gamma}_n$ to test the hypothesis that $\beta = 0$ (by testing whether $\gamma_n = 0$ for all n). This hypothesis is rejected at any conventional confidence level. The third step is to use the least-squares slope estimates to obtain the two indicators $\widehat{1}^*_{1n}$ and $\widehat{1}^*_{2n}$ that group countries by the direction of their comparative advantage.[9] We can then obtain an estimate of the effect of better contract enforcement on exports in relationship-specific input industries by applying 2SLS to (35) and instrumenting the interaction $z_{iUS}q_n$ with $z_{iUS}\widehat{1}^*_{1n}$, $z_{iUS}\widehat{1}^*_{2n}$, or both. We proceed using both instruments simultaneously as this is the most efficient approach. Using Nunn's baseline specification (in his Table IV), this yields a standardized beta coefficient of 0.361 with a standard error of 0.015. Nunn's estimate using the standard cross-industry cross-country benchmarking estimator is 0.289 with a standard error of 0.013. Hence, our new benchmarking estimator – which provides a lower bound on the strength of the true effect under assumptions (A1) and (A2) – yields that better contract enforcement is even more important for exports in relationship-specific input industries than the estimator of the cross-industry cross-country literature.

[9] The estimator $\widehat{1}^*_{1n}$ assigns countries with a positive least-squares slopes $\widehat{\gamma}_n$ a value of 1 and all other countries a 0. The estimator $\widehat{1}^*_{2n}$ assigns countries with a value for the quality of contract enforcement q_n above 0.588 a value of 1 and all other countries a 0 (that is $\widehat{q}^*_Q$ is estimated to be 0.588).

Figure 4: Country-Specific Slopes, Nunn (2007)



Notes: Country-specific least-squares slope estimates for the cross-industry cross-country model of Nunn (2007) plotted against the quality of contract enforcement.

4 Conclusion

Cross-industry cross-country models are used extensively in economics. The approach has attractive features, like its focus on theoretical mechanisms and the possibility to control for country-level determinants of economic activity. But there are also drawbacks. Implementation requires specifying technological industry characteristics that are generally unobservable and must therefore be proxied with industry characteristics in a benchmark country. That this can lead to an attenuation bias is unsurprising. What appears to not be understood is that using data from a benchmark country to approximate industry characteristics elsewhere can also lead to a (large) amplification bias when technologically similar countries are similar in other dimensions.

A main area of application of cross-industry cross-country models is international trade, where these models have been used to examine the effects of factor endowments and institutions on comparative advantage. We show that in this context there is an estimator that yields a lower bound on the true effect, as long as some countries differ in the direction of their comparative advantage.

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Appendix Table 1: Some applications of the cross-industry cross-country approach

#	topic	paper	industry characteristic (z) typically based on U.S. data	country characteristic (x)	main finding
effects of financial market development on economic growth, firm entry and exit and innovation					
1	finance and growth	Rajan and Zingales (1998)	industry dependence on external finance [ratio of capital expenditures minus cash flow over capital expenditures]	country financial development [market capitalization, private credit, measure of accounting standards]	sectors that depend for inherent technological reasons more on external sources of finance (debt and equity), as compared to internal sources (retained earnings), grow faster in financially developed countries
2	finance and growth	Claessens and Laeven (2003)	industry intangible intensity [ratio of intangible assets to net fixed assets]	country-level property rights protection [index of intellectual property rights, patent rights, risk of expropriation]	sectors with an asset mix tilted towards intangibles grow faster in countries with better property rights
3	finance and growth	Fisman and Love (2003)	industry dependence on trade credit [accounts payable to total assets]	country financial development [market capitalization, private credit, measure of accounting standards]	industries with higher reliance on trade credit grow faster in countries with weaker financial institutions
4	finance and growth	Fisman and Love (2007)	industry growth opportunities [sales growth]	country financial development [sum of domestic credit to private sector and market capitalization as a share of GDP]	industries with better growth opportunities grow faster in more financially developed countries
5	financial dependence and business cycles	Braun and Larrain (2005)	industry dependence on external finance	recession in country c at time t	industries that are more dependent on external finance are hit harder during recessions
6	credit constraints, entry	Aghion, Fally and Scarpetta (2007)	industry dependence on external finance	country financial development [sum of private credit and stock market capitalization as a share of GDP, state ownership of banks]	more small firms enter in more externally dependent sectors in more financially developed countries
7	finance and growth	Beck, Demirguc-Kunt, Laeven, and Levine (2008)	industry share of small firms [percentage of firms in each sector with less than 5, 10, 20, and 100 employees]	country financial development [private credit to GDP]	industries with a larger share of small firms grow faster in more financially developed countries
8	finance and R&D investment	Brown, Martinsson and Petersen (2013)	industry dependence on external finance	country financial development [value of IPOs as a share of GDP, accounting standards, anti-self-dealing index of shareholder protection]	firms in more externally financially dependent industries invest more in R&D in more financially developed countries and in countries with stronger shareholder protection
9	finance and innovation	Hsu, Tian and Xu (2014)	industry dependence on external finance and industry high-tech-intensity	country financial development [stock market capitalization, bank credit]	high-tech sectors that depend more on external sources of finance innovate more in financially developed countries

#	topic	paper	industry characteristic (z) typically based on U.S. data	country characteristic (x)	main finding
10	LTVs and collateral type	Calomiris, Larrain, Liberti and Sturgess (2016)	firm pledging of movable [machinery, inventory and accounts receivable] as opposed to immovable [real estate] collateral to secure a loan	country strength of collateral laws [sum of 7 binary coded variables on scope (what can, be pledged), monitoring and enforcement from World Bank "Doing Business"]	in countries with weak collateral laws, LTVs are lower for loans collateralized with movable assets
	international trade and industrial specialization				
11	factor proportions and trade	Romalis (2004)	industry factor intensities in skilled labour, unskilled labour, and physical capital	country factor endowments [human capital, physical capital, labour]	countries specialize in industries that intensively use factors that (a) they are already abundant in; (b) they are accumulating rapidly
12	human capital and growth	Ciccone and Papaioannou (2009)	industry skill intensity [average years of employee schooling, share of high-school and college graduates]	country initial human capital [averge years of schooling]	countries with higher initial education levels grew faster in schooling-intensive industries
13	institutions and trade	Nunn (2007)	industry contract intensity [proportion of non-standardized inputs (without a refereence price) used in production]	quality of contract enforcement and the judiciary [perception based rule of law index]	countries with good contract enforcement specialize in goods for which relationship-specific investments are most important
14	institutions and trade	Levchenko (2007)	industry dependence on differentiated inputs [concentration Herfindahl index of intermediate input use]	country institutional quality [rule of law]	countries with better institutions have a greater share of US imports in sectors using more intermediate inputs
15	institutions, trade and organizational choice	Ferguson and Formai (2013)	industry vertical integration-propensity and industry contract intensity	country judicial quality [rule of law]	benefits of judicial quality [high quality contractual institutions] for exports of contract-intensive goods are smaller in industries where firms are more likely to be integrated with their input suppliers
16	institutions and comparative advantage	Nunn and Trefler (2014)	industry cost sensitivity to quality of contracting institutions	country quality of contracting institutions	institutional sources of comparative advantage [as reflected by the interaction of country-level rule of law with industry-level contract intensity] are quantitatively as important as the impact of human capital and physical capital
17	financial liberalization and trade	Manova (2008)	industry dependence on external finance and industry asset tangibility [share of net property, plant and equipment in total book-value assets]	time-varying country equity-market openess and liberalization	liberalization increases exports disproportionately in sectors more dependent on outside finance or using fewer collateralized assets
18	credit constraints and trade	Manova (2013)	industry dependence on external finance and industry asset tangibility	country financial development [private credit to GDP]	more financially developed countries export more in sectors more dependent on outside finance or using fewer collateralized assets
19	credit constraints and trade	Manova, Wei and Zhang (2015)	sector financial vulnerability [external financial dependence, asset tangilibity, inventory/sales ratio, reliance on trade credit]	firm indicators for JV, MNC affiliates, firms with foreign ownership	foreign affiliates and JVs in China have better export performance than private domestic firms in financially more vulnerable sectors

#	topic	paper	industry characteristic (z) typically based on U.S. data	country characteristic (x)	main finding
20	finance and choice of export destinations	Chan and Manova (2015)	industry dependence on external finance and industry asset and industry asset tangibility	country financial development [private credit to GDP]	more financially developed countries have more trading partners and particularly so in financially dependent sectors
21	employment protection and investment	Cingano, Leonardi, Messina and Pica (2010)	sector worker reallocation intensity [average of normalized firm changes in employment in a country-industry cell]	country employment protection legislation [OECD produced weighted average of 18 basic items]	EPL reduces investment in high reallocation- relative to low reallocation-sectors
22	volatility, labour market flexibility and specialization	Cunat and Melitz (2012)	volatility of firm output growth [standard deviation of annual growth rate of firm sales]	country labour market flexibility [hiring-costs, firing costs, and restrictions on changing working hours as captured by World Bank index]	exports of countries with more flexible labor markets are biased towards high-volatility sectors
23	labour markets, education and trade	Tang (2012)	industry firm-specific skill intensity [estimated from Mincer wage regression with interaction of worker job tenure with industry dummy]	country labour market protection	countries with more protective labour laws export more in firm-specific skill intensive sectors at both intensive and extensive margins
24	labour market institutions and innovation	Griffith and Macartney (2014)	industry propensity to adjust to external labour market [layoff rate for 3-digit industry above or below the median layoff rate]	country employment protection legislation [weighted sum of sub-indicators for regular and temporary contracts and collective dismissals]	fewer radical innovations are done by high-layoff industries in countries with high EPL
25	pollution and comparative advantage	Broner, Bustos and Carvalho (2015)	industry pollution intensity [EPA-computed total air pollution per unit of output]	country laxity of air pollution regulation [proxied by outcome measure: grams of lead content per liter of gasoline]	countries with laxer environmental regulation have a comparative advantage in polluting industries
26	natural resources and comparative advantage	Debaere (2014)	sector water intensity [sector water withdrawals both direct and indirect (inputs) from US Geological Survey]	country water resources [volume of renewable fresh water per capita]	relatively water abundant countries export more water-intensive products
	outsourcing, FDI, and the fragmentation of production				
27	vertical vs horizontal, intra vs inter industry FDI	Alfaro and Charlton (2009)	industry skill intensity [ratio of nonproduction to total workers]	country skill abundance [average years of schooling]	vertical FDI appears driven by comparative advantage at 2-digit level but not at 4-digit level
28	sourcing of goods of different complexity	Carluccio and Fally (2012)	product complexity [measured with different indicators of R& D expenditures]	country financial development [private credit to GDP]	complex goods are more likely sourced from more financially developed countries

#	topic	paper	industry characteristic (z) typically based on U.S. data	country characteristic (x)	main finding
29	offshoring	Basco (2014)	industry R&D intensity [average industry R&D expenditure]	country financial development [share of domestic credit to private sector over GDP]	more R&D intense industries use more intermediate inputs (offshore more) in more financially developed countries
30	infrastructure and FDI	Blyde and Molina (2015	industry dependence logistic services [firm-in-industry willingness to pay for air shipping to avoid an additional day of ocean transport]	country logistic infrastructure [number of ports and airports above a certain size normalized by country population]	countries with better logistic infrastructure attract more vertical FDI in more time-sensitive industries
31	corruption and innovation	Paunov (2016)	industry usage intensity of quality certificates and patents [share of firms holding quality certificates; fractional patent count to value added]	country corruption [share of firms reporting gift required to obtain operating license]	firms in industries with greater reliance on quality certificates own less such certificates in more corrupt countries
32	firm size and growth	Pagano and Schivardi (2003)	sector R&D intensity [share of R&D personnel in total em ployment, ratio of R&D to total investment and value added]	average firm size of firm in sector in country [measured by employment]	sectors with larger average firm size grow faster; particul larly in R&D intense sectors
33	regulation and entry	Klapper, Laeven and Rajan (2006)	industry natural propensity to high entry [fraction of firms in industry that is one or two years old]	country entry regulation [cost of business registration; in per capita GNP, time, or procedures]	costly regulations reduce firm creation, especially in industries with naturally high entry
34	regulation and entry	Ciccone and Papaioannou (2009)	employment re-allocation [industry employment growth]	country entry regulation [time and procedures to register a new business]	countries where it takes less time to register new businesses have seen more entry in industries that experienced expansionary global demand and technology shifts
35	determinants of vertical integration	Acemoglu, Johnson, and Mitton (2009)	industry capital intensity as a proxy for vulnerability to holdup problems [fixed assets to sales]	country-level contracting costs [procedural complexity, contract enforcement procedures, legal formalism]	firms in industries with higher capital-intensity are more vertically integrated in countries with higher contracting costs
36	aid and manufacturing growth	Rajan and Subramanian (2011)	industry sensitivity to exchange rate appreciation [industry ratio of exports to value above or below the median]	country receipts of foreign aid	industries more sensitive to exchange rate appreciations grew relatively more slowly in countries receiving larger aid inflows
37	international financial flows and growth	Aizenman and Sushko (2011)	industry dependence on external finance	portfolio equity, debt, and FDI inflows in country c at time t	equity inflows have negative aggregate growth impact but positive impact in more financially constrained industries; FDI inflows have positive impact, both at the aggregate level and more external finance dependent industries

#	topic	paper	industry characteristic (z) typically based on U.S. data	country characteristic (x)	main finding
38	human capital and trade	Bombardini, Gallipoli and Putato (2012)	industry skill substitutability [residual wage dispersion; rankings on teamwork, impact on co-woker output and communication / contact]	country skill dispersion [within-country standard deviation of log scores on standardised tests]	countries with more dispersed skill distributions export more in sectors with high substitutability of workers' skills
39	business risk and growth	Michelacci and Schivardi (2013)	sector idiosyncratic risk [sectoral component of volatility of firm stock returns]	country lack of diversification opportunities [importance of family firms in the economy; share of widely held firms in the economy]	OECD countries with low levels of risk diversification opportunities perform relatively worse in sectors with high idiosyncratic risk
40	capital account openness and inequality	Larrain (2014)	industry dependence on external finance and capital-skill complementarity [external financial dependence as Rajan and Zingales (1998); capital intensity elasticity of skilled wage share]	timing of country capital account opening	capital account openness increases sectoral wage inequality, particularly in industries with both high external finance dependence and strong capital-skill complementarity
41	intellectual property rights and innovation	Aghion, Howitt, and Prantl (2014)	industry reliance on patents [R&D expenditure to nominal value added; patent count]	EU wide product market reform interacting with country-level strength of patent rights [data on patent law reforms]	1992 EU product market reform led to more innovation in countries with stronger patent protection and in particular in industries relying more on patents
42	real effects of banking crises	Dell'Ariccia, Detragiache, and Rajan (2008)	industry dependence on external finance	banking crisis in country c at time t	sectors relatively more dependent on external finance perform worse during banking crises
43	banking crises and exports	Iacovone and Zavacka (2009)	industry dependence on external finance	banking crisis in country c at time t	during a crisis, exports of sectors more dependent on external finance grow relatively less than those of other sectors
44	investment effect of the subprime mortgage crisis	Duchin, Ozbas, and Sensoy (2010)	industry dependence on external finance	before/after sub-prime crisis	decline in corporate investment is sharpest in industries with high external financial dependence
45	transmission of financial crises	Claessens, Tong, and Wei (2012)	industry dependence on external finance and trade sensitivity [global GDP elasticity of global exports at 3-digit sector level]	country trade openness and fiscal and monetary policy	crisis hit firms more sensitive to trade and business cycles hardest, especially in countries more open to trade
46	firm growth and bank recapitalization	Laeven and Valencia (2011)	industry dependence on external finance	country bank recapitalization policies [committed amounts of public recapitalization funds]	growth of finance dependent firms is disproportionately positively affected by bank recapitalization

#	topic	paper	industry characteristic (z) typically based on U.S. data	country characteristic (x)	main finding
47	monetary policy and growth	Aghion, Farhi, and Kharroubi (2015)	industry credit or liquidity constraints [asset tangibility measured by value of net property, plant and equipment to total assets for credit constraints; labor-cost to sales for liquidity constraints]	degree of counter-cyclicality of short-term interest rates [coefficient on output gap in regression with ST-rates on LHS]	credit or liquidity constrained industries grow more quickly in countries with more counter-cyclical short-term interest rates
48	fiscal policy and industry growth	Aghion, Hemous, and Kharroubi (2014)	industry dependence on external finance	countercyclicality of country fiscal policies [coefficient on output gap in regression with fiscal balance to GDP on LHS]	more externally dependent industries grow faster in countries that implement more countercyclical fiscal policies
	economic effects of differences in financial development, institutional quality and trust across regions and time				
49	entry and access to finance	Cetorelli and Strahan (2006)	industry external financial dependence	degree of concentration in local banking markets [two policy variables on within-state branching and inter-state-banking restrictions; deposit Herfindahl concentration index]	sectors with greater external financial dependence have larger and fewer firms in more concentrated local banking markets
50	real effects of banking deregulation	Bertrand, Schoar, and Thesmar (2007)	industry reliance on bank financing [all debt excluding trade credit and bonds over total outside financing (debt and book value of equity)]	before/after 1985 French bank reform	industries more reliant on bank financing before 1985 deconcentrated and experienced faster employment growth post bank-reform
51	corporate tax reform and growth	Hsieh and Parker (2007)	industry dependence on external finance	before / after 1984 Chilean corporate tax reform	post-reform investment boom occurred primarily in industries more dependent on external finance
52	credit constraints and cylicality of R&D investment	Aghion, Askenazy, Berman, Cette and Eymard (2012)	industry dependence on external finance or asset tangility	business cycle in France	for industries more reliant on external finance or with low asset tangibility, R&D investment is countercyclical without credit constraitns, and becomes pro-cyclical with tighter credit constraints
53	institutions and trade in China	Feenstra, Hong, Ma, and Spencer (2013)	industry reliance on contracts [from Nunn (2007), differentiation of intermediate inputs]	cross-provincial variation in institutional quality in China [court efficiency as measured by overall quality, delays of verdicts and court costs]	firms in industries using more differentiated inputs export firms, more if they are located in Chinese regions with better courts

#	topic	paper	industry characteristic (z) typically based on U.S. data	country characteristic (x)	main finding
54	firm growth and access to finance in Morocco	Fafchamps and Schündeln (2013)	sectoral growth opportunities [value added growth 1998-2003]	local bank availability [dummy = 1 if local commune has a bank]	firms in sectors with better growth opportunities grow faster in localities with bank availability
55	unemployment, recessions and financing constraints	Duygan-Bump, Levkov, and Montoriol-Garriga (2015)	industry dependence on external finance	US recessions 90-91, 2001, 2007-2009	workers in small firms are more likely to become unemployed if they work for firms in industries with high dependence on external finance during recessions in which loan supply contracts
56	trade credit chains and corporate failure	Jacobson and von Schedvin (2015)	industry dependence on external finance and liquidity [latter measured by inventory / sales ratio]	failure of trade credit debtors in Sweden	propagation of corporate failure from trade-debtor to creditor is particularly severe in finanically constrained industries
57	trust and trade	Cingano and Pinotti (2016)	industry delegation intensity [regression based measure: part of variation of number of responsibility centres in a region-industry explained by industry fixed effects]	region / country trust [survey data]	high-trust regions and countries specialize in delegation intensive industries