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Import competition and firm productivity: Evidence from German manufacturing

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Abstract
We study how different types of import competition affect firm productivity using firm-product data from German manufacturing (2000–2014). Competition from high-income countries causes affected domestic firms to increase their productivity and lower their prices. Oppositely, import competition from low-wage countries does not lead to firm productivity gains. Instead, domestic firms' sales and input usage decline. Our findings confirm the intuition of ladder models that the effect of competition depends on the "closeness" of competitors. They are in line with widespread X-inefficiencies throughout the economy, which firms reduce in response to competition from high-income countries.

KEYWORDS
import competition, multi-product firms, productivity

1 | INTRODUCTION

There is a widespread consensus that trade liberalisation and increasing firm competition yield aggregate welfare gains. Generally, competition threatens firms' rents and even their existence. Firms take costly actions to improve efficiency to escape competition, and if firms cannot survive, their resources will be allocated to more productive producers (Aghion et al., 2004, 2005, 2009; Holmes & Schmitz, 2010). Yet, while research has studied the reallocation effects of international trade (e.g., Melitz, 2003), empirical evidence regarding the direct firm-level productivity effects of import competition is scarce and controversial (Autor et al., 2020; Bloom et al., 2016; Campbell

& Mau, 2019). Therefore, more evidence based on detailed, high-quality data is required to better understand how import competition affects individual firms and how this shapes gains from trade (see Shu & Steinwender, 2019 for a review of existing evidence).

We provide such evidence by studying the effects of firm-level import competition on firm-level productivity using unusually rich and representative firm-product-level data for the German manufacturing sector (2000–2014). Our data cover the rise of low-income imports following China's WTO accession and the years leading up to the TTIP and CETA trade negotiations between the EU and other high-income countries. Our main result shows that competition can increase firm productivity, but that the effect ultimately depends on the type of competition domestic firms face. Although competition from low-income countries has no direct effect on firms' productivity, competition from other high-income countries causes German firms to improve their productivity. Our identification relies on a well-established IV-2SLS strategy that instruments domestic imports with imports from third countries. This instrument reflects the genuine competitiveness of the foreign trade partners and is exogenous to unobserved confounders (Autor et al., 2013; Goldsmith-Pinkham et al., 2020).

We also use rich firm data to markedly improve the precision of previous estimates: Most notably, our data contain information on the quantities and prices for firms' individual final products. From this information, we construct *firm-specific* import competition measures as sales-weighted averages of observed import competition for each product in the data. This allows us (i) to address that competition takes place on firm-specific output markets rather than within (broadly defined) industries and (ii) to separate the effect of import competition from other channels that affect firm productivity, such as access to better and/or cheaper inputs. The latter distinction is impossible if competition is measured at the industry level (the usual practice in most studies) because industry imports consist of final and intermediate goods (Ahn & Duval, 2017; Goldberg et al., 2010; Halpern et al., 2015; Kasahara & Rodriguue, 2008; Lileeva & Trefler, 2010; Young, 1991). In contrast, we can precisely identify final good competition.

Moreover, our information on product prices allows us to back out a quantity-based productivity measure (TFPQ) that, in contrast to widely applied revenue-based productivity measures (TFPR), is not confounded by firm prices. This avoids the common underestimation of the effect of competition on firm productivity if output prices decline in response to competition (De Loecker, 2011; Eslava et al., 2004; Foster et al., 2008; Smeets & Warzynski, 2013).

As noted, we distinguish between import competition from high- and low-income countries, which accounts for differences in the characteristics of imports and for comparative advantages of domestic firms. We show that imports from high-income countries threaten capital- and R&D-intensive domestic products, whereas imports from low-income countries threaten labour-intensive products. This is in line with studies documenting that low-income countries specialise in labour-intensive goods that use comparably simple technologies and are characterised by lower unit costs of production, whereas high-income countries have a comparable advantage in producing capital-intensive and technologically sophisticated products (Amiti & Khandelwal, 2013; Cali et al., 2016; Hummels & Klenow, 2005; Khandelwal, 2010; Schott, 2004).

To shed further light on the mechanism driving firms' productivity adjustments, we analyse the effects of import competition on a full spectrum of firm variables to understand how firms adjust their behaviour in response to competition. Particularly, we study firms' physical output, prices, employment, capital stocks, intermediate input expenditures, wage payments, and R&D investment, which provides additional insights on firms' reactions. Compared to previous research, our study therefore provides a much more comprehensive understanding on the effects of import competition on firm productivity.

Firms respond to high-income country import competition by reducing output prices and input usage while increasing output quantities which explains the positive productivity effect. Firms do not lower prices in response to competition from low-income countries and instead experience a fall in sold quantities and input usage explaining the absence of any productivity effects from low-wage country competition. For German manufacturing firms, reducing prices and increasing productivity apparently pays off as a mean to cope with competition from other industrialised, high-income countries. Oppositely, high-wage German manufacturing firms are at a relative disadvantage when competing with firms from low-income (low-wage) countries. This creates incentives to downsize and give up market shares.

Interestingly, R&D investment does not increase in response to competition. The documented productivity enhancing effect of high-income country competition is therefore not a consequence of increased R&D activities. Instead, it must result from firms realising existing, unused potential to raise efficiency. Firms might operate below their maximum efficiency either because management consumes a part of firms' rents as leisure (Biggerstaff et al., 2017) or because of true ignorance about better technology (Bloom & Van Reenen, 2010). Both hypotheses are consistent with our findings. We supplement studies documenting similar "X-inefficiencies" in narrowly defined sectors like health care (Bloom et al., 2015) or the oil industry (Borenstein & Farrell, 2000) by providing evidence for a reduction in inefficiencies after competition shocks across a large set of firms and industries.

The differential effects of competition from high- and low-income countries are not an artefact of both competition types threatening different products and, therefore, firms that systematically differ in their characteristics: We show that the results hold when excluding firms predominantly hit by either type of competition and when conducting the analysis only for firms facing comparable levels of competition from both types of countries simultaneously.

Moreover, the differential effects of competition from high- and low-income countries do not result from high- and low-income competition specifically threatening core products versus non-core products. In a specification that simultaneously includes both types of import competition, each with respect to core and non-core products, we find a productivity enhancing effect of competition only for high-income competition threatening firms' core products.

Our study complements empirical research on the impact of Chinese imports on firms in industrialised economies (e.g., Autor et al., 2020; Bloom et al., 2016; Dhyne et al., 2017). Bloom et al. (2016) use Amadeus data on 8000 firms across 12 European countries and find that China's share in total imports is positively associated with increases in innovation (patenting and R&D) and TFPR.[1] According to Bloom et al. (2013, 2021), the positive effect on innovation results from trapped factors used in the production of goods hit by Chinese import competition being "released" and reallocated to R&D activities within firms. Although our findings of positive productivity effects from competition hitting core products are consistent with such a mechanism, we find a negative effect on R&D investment from low-wage competition. This is in line with Autor et al. (2020), who find that higher exposure to Chinese import competition is associated with a reduction in R&D (and sales and employment) for publicly traded companies in North America. Our findings also relate to Dhyne et al. (2017), who document that the incentives of Belgian firms to increase productivity are higher when higher-ranked products are hit by Chinese import competition.

However, the differences in the effects of import competition from different countries that we document indicate also differences in the ability of domestic firms to compete with certain types of competitors. Our results are in line with Aghion et al. (2005) who highlight that the marginal payoff to innovation in response to "dominant" competitors (i.e., low-wage competition) declines at "laggard" (high-wage domestic) firms. Our findings correspond also with Bernard et al. (2006a), Mion and Zhu (2013), and Auer et al. (2013), who provide evidence that price competition from low-wage countries results in a decline in employment and firm survival in industrialised countries.

[1]See Campbell and Mau (2019) for a discussion of the robustness of the results in Bloom et al. (2016).

Our article also connects to the trade literature that studies firm heterogeneity in productivity highlighting that the effects of trade liberalisation depend on the relative performance of domestic firms. In Melitz (2003), international competition results in less productive firms declining or exiting the market, while the reallocation of market shares to higher-productivity firms generates aggregate productivity gains. Bernard et al. (2003) and Bernard et al. (2007) show how such reallocation processes strengthen comparative advantages in the aggregate. We complement this literature by focusing on *within-firm* effects.

Finally, our study connects to empirical work on the effects of a reduction in trade costs on firm performance (Amiti & Konings, 2007; Bernard et al., 2006a, 2006b; De Loecker, 2011; Pavcnik, 2002; Topalova & Khandelwal, 2011; Trefler, 2004). We add to this literature by analysing the role of import competition.

The remainder proceeds as follows. Section 2 introduces the administrative data on German manufacturing firms and describes the measurement of firm-specific import competition and firm productivity. Section 3 details our econometric strategy to assess the impact of import competition on firm productivity. Section 4 presents results. Section 5 concludes.

2 | DATA AND MEASURING IMPORT COMPETITION AND PRODUCTIVITY

2.1 | Firm-product data

Our firm data come from the yearly Structural Business Surveys (AFiD thereafter) that cover the universe of German manufacturing firms with at least 20 employees and are maintained by the German Statistical Offices.[2] In our analysis, we use an unbalanced panel of about 16,000 firms for the period 2000–2014 because some variables required for estimating firm productivity are collected only for a 40% subsample that rotates every 4–5 years. As this subsample is stratified by industry and size class, which are variables observed for all firms in AFiD, we construct inverse probability weights to ensure the representativeness of our results for the whole population in AFiD.[3]

AFiD contain detailed information on quantities and factory gate prices for firms' final products at the nine-digit PRODCOM classification. This information allows us to measure *firm-specific* import competition (Section 2.2), which, compared to industry-level measures, (i) accounts for competition taking place on firm-specific output markets rather than within broadly defined industries and (ii) allows us to disentangle final product import competition from intermediate input imports.[4] Additionally, the product quantity and price information also allows us to derive a quantity-based productivity measure (TFPQ) that is not confounded by firm-specific price effects (Section 2.3).

2.2 | Measuring firm-specific import competition

We measure product-level import competition as the product-specific market share of foreign imports. We then compute firm-level import competition as the sales-weighted average of our product import competition measures in firms' product portfolio. To construct these measures, we combine information

[2]Data source: RDC of the Federal Statistical Office and Statistical Offices of the Federal States, DOI: 10.21242/42131.2017.00.03.1.1.0, 10.21242/42221.2018.00.01.1.1.0, and 10.21242/42111.2018.00.01.1.1.0.

[3]We clean the data from top and bottom one per cent outliers with respect to sales over production inputs and sales growth. We also clean the price data from the top and bottom one per cent outliers with respect to product price deviations from average product prices.

[4]For instance, car bodies and finished cars both belong to the sector code (NACE 29). Yet, car bodies are an input for car producers and should not be measured as import competition.

on firms' final products and United Nations' Comtrade data on the value of the total German imports by product (UN Statistics Division, 2009). Formally, we measure import competition from country group n as:

$$IC_{it}^{n} = \sum_{g} \left[\left(\frac{R_{igt}}{\sum_g R_{igt}} \right) \left(\frac{M_{gt}^{n}}{M_{gt}^{World} + \sum_i R_{igt}} \right) \right] * 100, \quad (1)$$

where g, i, and t indicate the product (PRODCOM, eight-digit-level), firm, and time dimensions.[5] In g, we use only final goods actually produced by a firm (not purchased goods for resale or inputs). This ensures that intermediate input imports do not confound the competition measure. R_{igt} and $\sum_g R_{igt}$ are a firm's sales of product g and total sales, respectively. Thus, the first fraction in (1) is the firm-level revenue weight of product g. $\sum_i R_{igt}$ denotes the value of total domestic production of product g, M_{gt}^{World} is the value of total imports of product g, and M_{gt}^{n} is the value of the total imports of product g from a country(−group) n, where $n = (High, Low)$ indicates high- and low-income countries. Thus, the second fraction is the market share of imports from country group n for product g. We define the high-income country group as USA, Canada, Japan, and South Korea. The low-income country group includes China, India, Russia, Brazil, South Africa, Argentina, Chile, Mexico, Malaysia, Turkey, Thailand, Tunisia, Bangladesh, Indonesia, Philippines, Vietnam, and Pakistan.[6]

We do not consider other European high- and low-income countries in the definition of our high- and low-income country group to (i) minimise the problem of European subsidiaries of German firms contributing towards our import competition measure and (ii) to further ensure that our import competition measure does not capture any significant intermediate input trade flows. Even though we observe final product production in our data, there might be intermediate products imported from European subsidiaries as intermediates that are classified by the same product code as the final product manufactured out of these unfinished products. Excluding European countries from our analysis minimises the threat of this identification problem.

Nevertheless, although we prefer the above country definitions, we conduct a robustness test in Appendix S5.1 in which we find qualitatively similar results after including several other European countries into the high-income country group. Furthermore, in our above country group definition, we exclude several other high-income countries that we require for our instrument approach (see Section 3). We are aware that neither country group is complete, but our identification strategy requires us to leave out a number of important competitors. Overall, we believe that the countries included represent the respective groups reasonably well and that we compromise neither the generalisability nor the robustness of our results.

We allow for import competition from high-income and low-income countries because the utilised production factor mix, technology intensity, and other characteristics of the production process differ between the products of these country groups (despite they might enter the same product code). In line with the trade patterns predicted by the comparative advantage framework, imports from high-income countries should be comparably capital-intensive, technologically sophisticated, use high-quality and expensive inputs, and have a relatively high innovation potential (e.g., Hummels & Klenow, 2005; Schott, 2004). These are products, in which also German firms tend to specialise. Oppositely, products from low-income countries are typically relatively labour-intensive, technologically less sophisticated,

[5]As the data do not contain information on exports at the firm-product level, we follow Mion and Zhu (2013) and exclude exports from the denominator.

[6]We do not consider countries with negligible shares in the total imports of the German manufacturing sector (e.g., Afghanistan).

TABLE 1 Characteristics of domestic firms facing import competition from high- and low-income countries.

	Firms predominantly exposed to import competition from high-income countries (mean / median)	Firms predominantly exposed to import competition from low-income countries (mean / median)
IC_{it}^{High}	13.44/10.63	1.29/0.63
IC_{it}^{Low}	1.79/1.30	20.22/13.41
K/L (€/FTE)	123,185/83,251	92,076/68,846
R&D/L (€/FTE)	5926/1683	1340/0
R&D/Sales (%)	3.05/1.06	0.76/0

Notes: Firms are exposed predominantly to import competition from high−/low-income countries, if competition from high−/low-income countries is at least three times larger than competition from low−/high-income countries. Import competition from high-income countries and from low-income countries is calculated according to equation (1). The capital-to-labour ratio, *K/L*, is measured in Euros per full-time equivalent (FTE). *R&D/L* is R&D expenditures per FTE. *R&D/Sales* is R&D expenditures over total sales (in %).

have a lower innovation potential, and a lower unit cost of production. Regarding such products, German (high-wage) firms are at a relative disadvantage on international markets. These differences in characteristics of imported goods imply differences in the type of competition associated with low- and high-income country imports.

Table 1 compares domestic firms that are predominantly exposed to high-income import competition with firms predominantly exposed to low-income import competition. We use this information to approximate the characteristics of imports from the two types of countries as the trade data do not contain information about product characteristics. We define firms to be exposed predominantly to import competition from high-income countries, if competition from high-income countries is at least three times larger than competition from low-income countries (and vice versa). Our findings indicate that high-income country imports are more capital- and R&D-intensive than low-income country imports. The capital-labour ratio of firms facing predominantly high-income country competition is on average 34% higher (about 21% for the median firm) than the capital-labour ratio of firms facing predominantly low-income country competition. R&D expenditures of firms facing mostly high-income competition are four times larger compared to R&D expenditures of firms facing mainly low-income import competition.

In unreported statistics, we further find that import penetration from low-income countries is high in rather basic and comparably labour-intensive industries (e.g., clothing, fabricated metal products) as well as in sectors using comparably simple technologies (e.g., household and consumer electronics). Oppositely, high-income country import competition is large in industries that use advanced and high-end technologies (e.g., chemical products, electrical and optical equipment, medical and precision instruments) or that are R&D-intensive (e.g., pharmaceuticals).

Finally, Figure 1 displays the evolution of our firm-level import competition measures (averages). Although low-income country import competition significantly increased over the observation period, import competition from high-income countries stagnated. This reflects the increasing importance of low-wage countries as German trade partners in recent decades (most notably China).[7]

[7]If we include other European high-income countries (as used in our robustness check in online Appendix S5.1), we find a similar trend in high-income import competition. Yet, the level exceeds the level of low-income import competition in that case. As becomes clear below, our regressions use firm fixed effects and relate changes in import competition to changes in firm productivity. Thus, the level difference does not affect our results.

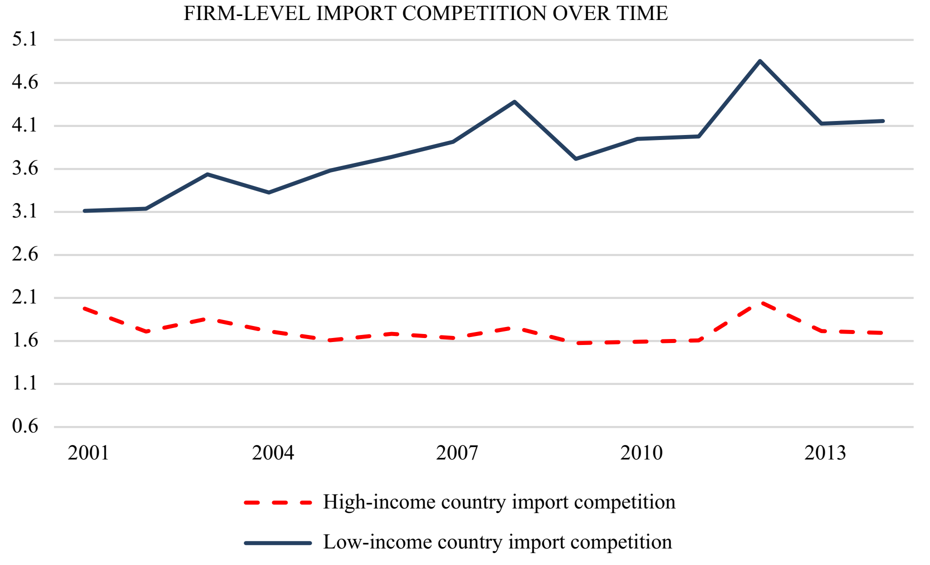

FIGURE 1 Average firm-level import competition from high- and low-income countries (as defined in equation (1)) over time. The red dashed line displays import competition from high-income countries. The blue solid line displays import competition from low-income countries. German manufacturing sector data. 2001–2014. [Colour figure can be viewed at wileyonlinelibrary.com]

2.3 | Assessing firm productivity

Our main research question is whether firms increase productivity in response to competition. Thus, it is key to derive a measure that reflects the true productivity of firms and which is not confounded by price differences between firms.

We assume that firms produce output with a Cobb–Douglas technology:

$$Q_{it} = L_{it}^{\beta^l} K_{it}^{\beta^k} M_{it}^{\beta^m} \Omega_{it} \tag{2}$$

Q_{it} denotes total sales of firm i in period t and is deflated with a firm-specific index for the price of the composite output of each individual firm, based on information on final products' quantities and prices in the data (see online Appendix S1). This allows us to purge firm-specific output quality and price differences and to interpret Q_{it} as quasi-physical output (Eslava et al., 2004). Labour, L_{it}, is measured in full-time equivalents. K_{it} and M_{it} are capital stocks and intermediates input expenditures, deflated with respective two-digit industry deflators from the German Federal Statistical Office.[8] Total factor productivity, Ω_{it}, is a Hicks-neutral shifter. Because Q_{it} can be interpreted as quasi-physical output, Ω_{it}, can be interpreted as quantity-based TFP (TFPQ), which, compared to revenue-based TFP (TFPR), is not confounded by unobserved firm-specific factors that influence output prices (Eslava et al., 2004; Foster et al., 2008). The latter is particularly important in our case, as import competition might affect firms' output prices. Taking logs of (2) yields our empirical production function:

$$q_{it} = \beta^l l_{it} + \beta^k k_{it} + \beta^m m_{it} + \omega_{it} + \varepsilon_{it}. \tag{3}$$

Smaller letters denote logs and ε_{it} is an i.i.d. disturbance.

[8]See Appendix S2 for the construction of the capital series.

We also include the price of firms' composite output, π_{it}, on the right-hand side of the production function (3) to account for unobserved quality differences in intermediate and capital inputs (De Loecker et al., 2016; Fox & Smeets, 2011).[9] We follow De Loecker et al. (2016) who argue that, whenever input quantities and prices are not available, observed output prices can be used as a proxy for input quality if expensive high-quality products require expensive high-quality inputs. Hence, the estimation specification becomes:

$$q_{it} = \beta^l l_{it} + \beta^k k_{it} + \beta^m m_{it} + \gamma \pi_{it} + \omega_{it} + \varepsilon_{it}. \tag{4}$$

One remaining issue in equation (4) is that ω_{it} is unobserved. We therefore follow the control function approach by Olley and Pakes (1996) and assume that firms know their productivity, ω_{it}, when making decision about flexible inputs. Hence, these flexible inputs can be used to proxy for productivity in equation (4). In line with Levinsohn and Petrin (2003), we use raw material expenditures (which are components of total intermediates), denoted by e_{it}, to proxy for productivity. We assume that capital and labour do not respond to productivity innovations.[10] Assuming that firm's demand for raw materials is monotonic in ω_{it} allows us to write the inverted demand function for e_{it} as:

$$\omega_{it} = g_{it}(.) = g_{it}(k_{it}, l_{it}, e_{it}, \boldsymbol{z}_{it}), \tag{5}$$

which defines our control function for productivity. $\boldsymbol{z}_{it}$ captures additional variables that account for further firm-specific factors that might affect firms' demand for raw materials. Following De Loecker et al. (2016), $\boldsymbol{z}_{it}$ is specified as broadly as possible and includes firms' number of products, an export dummy, a dummy variable for R&D activities, dummy variables for firms' four-digit industry, Federal State dummies for firms' headquarter location, and firm-level import competition (as defined in Section 2.2).[11]

Assuming that ω_{it} follows a Markov process, $\omega_{it} = \omega_{it-t} + \xi_{it}$, where ξ_{it} denotes the innovation to productivity, yields:

$$q_{it} = \beta^l l_{it} + \beta^k k_{it} + \beta^m m_{it} + \gamma \pi_{it} + g_{it-1}(.) + \xi_{it} + \varepsilon_{it}. \tag{6}$$

We estimate (6) using a one-step approach as in Wooldridge (2009) and instrument m_{it} and π_{it} with their lags. The identifying moments are given by:

$$E\left(\xi_{it} + \varepsilon_{it} \mid l_{it}, \tilde{k}_{it}, \tilde{m}_{it-1}, l_{it-1}, \tilde{k}_{it-1}, \tilde{e}_{it-1}, \boldsymbol{z}_{it-1}, \boldsymbol{\Gamma}_{it-1}, \pi_{it-1}\right) = 0, \tag{7}$$

where $\boldsymbol{\Gamma}_{it}$ collects interaction terms entering $g_{it}(.)$.[12]

Total factor productivity (TFPQ) can be recovered as:

$$\hat{\omega}_{it} = q_{it} - \left(\hat{\beta}^l l_{it} + \hat{\beta}^k k_{it} + \hat{\beta}^m m_{it} + \hat{\gamma} \pi_{it}\right). \tag{8}$$

[9] We define π_{it} as the sales-weighted average of firms' product price deviations from product-wide average prices. The sales weights for each product of a firm are the sales of a firm's product in total firm sales.

[10] These timing assumptions are consistent with De Loecker et al. (2016). They are also in line with relatively strong labour market regulations and labour market rigidities in Germany (see OECD, 2018).

[11] As we estimate the production function in one step following Wooldridge (2009), the variables included in $\boldsymbol{z}_{it}$ also control for any productivity shifting actions of firms as mentioned, for instance, in De Loecker (2013).

[12] We define $g_{it}(.)$ as a third-order polynomial in k_{it}, l_{it} and e_{it}, while variables in $\boldsymbol{z}_{it}$ enter linearly.

TABLE 2 Production function estimates – Output Elasticities.

NACE rev. 1.1 two-digit industries	Number of observations	Intermediate inputs	Labour	Capital	Returns to scale
15 Food products and beverages	16,566	0.67*** (0.02)	0.22*** (0.02)	0.16*** (0.04)	1.05
17 Textiles	3925	0.76*** (0.03)	0.25*** (0.04)	0.01 (0.04)	1.02
18 Apparel, dressing, and dyeing of fur	1367	0.77*** (0.03)	0.18*** (0.04)	0.04 (0.05)	0.99
19 Leather and leather products	778	0.75*** (0.04)	0.22*** (0.05)	0.12 (0.09)	1.08
20 Wood and wood products	2850	0.70*** (0.03)	0.25*** (0.04)	0.01 (0.05)	0.96
21 Pulp, paper, and paper products	3618	0.81*** (0.03)	0.18*** (0.04)	0.03 (0.02)	1.02
24 Chemicals and chemical products	7030	0.76*** (0.02)	0.22*** (0.04)	0.06 (0.04)	1.05
25 Rubber and plastic products	7835	0.69*** (0.03)	0.10 (0.08)	0.04 (0.03)	0.83
26 Other non-metallic mineral products	6747	0.74*** (0.02)	0.26*** (0.03)	0.02 (0.03)	1.02
28 Fabricated metal products	12,944	0.72*** (0.02)	0.27*** (0.05)	0.08** (0.03)	1.04
30 Electrical and optical equipment	631	0.82*** (0.09)	0.21*** (0.09)	0.28** (0.13)	1.31
31 Electrical machinery and apparatus	5402	0.68*** (0.03)	0.26*** (0.04)	0.10*** (0.04)	1.05
32 Radio, television, and communication	1257	0.77*** (0.05)	0.04 (0.11)	0.12 (0.12)	0.93
33 Medical and precision instruments	3279	0.61*** (0.03)	0.23*** (0.05)	0.11 (0.08)	0.96
34 Motor vehicles and trailers	2881	0.81*** (0.07)	0.15*** (0.05)	0.04 (0.06)	1.00
36 Furniture manufacturing	4287	0.75*** (0.03)	0.17*** (0.05)	0.04 (0.04)	0.96

Notes: This table reports output elasticities for labour, capital, and intermediate inputs obtained from separate estimations of the production function (6) for each NACE rev. 1.1 two-digit industry with at least 500 observations. All regressions include time fixed effects and are weighted using inverse probability weights. Standard errors are clustered at the firm level and reported in parentheses. Significance: *10 per cent, **5 per cent, ***1 per cent.

To allow for differences in production technologies across sectors, we estimate (6) separately for NACE rev. 1.1 two-digit industries with at least 500 firm-year observations.[13]

Table 2 reports output elasticities of capital, labour, and intermediate inputs from industry-specific estimations of the production function (6). Overall, we estimate a firm-level production function for

[13]We subtract $\hat{\gamma}\pi_{it}$ from q_{it} because $\hat{\gamma}\pi_{it}$ captures *input* price variation in our regression framework. This is consistent with De Loecker et al. (2016).

16 NACE rev. 1.1 two-digit industries with roughly 100,000 firm-year-observations.[14] The estimated output elasticities are plausible and in line with firm-level production function estimates from other studies (Amiti & Konings, 2007; De Loecker, 2011; De Loecker et al., 2016; Dhyne et al., 2017; Mertens, 2020, 2022; Pavcnik, 2002).[15]

3 | IDENTIFYING THE PRODUCTIVITY EFFECTS OF IMPORT COMPETITION

To assess the effect of import competition on firm productivity, we estimate the following specification:

$$\hat{\omega}_{ijt} = \boldsymbol{IC}_{it-1}^{low}\beta^{low} + \boldsymbol{IC}_{it-1}^{high}\beta^{high} + \boldsymbol{C}'_{it-1}\gamma + \vartheta_t + \theta_{ij} + \varepsilon_{ijt}, \tag{9}$$

where $\hat{\omega}_{ijt}$ is firm total factor productivity. $\boldsymbol{IC}_{it-1}^{n}$ is lagged import competition from high- and low-income countries ($n = (high, low)$). We jointly include competition from high- and low-income countries to compare their effects on productivity. $\boldsymbol{C}'_{it-1}$ includes controls for the number of products to account for systematic differences between single- and multi-product firms and export intensity (export share in total sales) to account for further firm-specific shocks on foreign markets and/or learning by exporting (Clerides et al., 1998; De Loecker, 2013). ϑ_t are time fixed effects and θ_{ij} are firm-industry fixed effects to account for the empirical production function being estimated separately by industries, j. We therefore use within-firm variation to identify the effect of import competition on firm productivity. We apply (inverse probability) weights to ensure representativeness of our estimates.

We estimate (9) by OLS and IV-2SLS. The latter gives us more confidence in drawing causal inference as OLS estimates might suffer from endogeneity issues. For instance, unobserved domestic demand and supply shocks could affect trade, which might confound our OLS estimates. Moreover, the market share of foreign firms might be particularly large in markets where domestic firms are disadvantaged and have low incentives to invest in productivity. Additionally, there are several potential mechanisms through which reverse causality might bias our results towards zero. First, decreasing productivity of domestic German firms, c.p. reduces German aggregate production and thus mechanically increases our competition measure. Second, decreasing domestic productivity encourages foreign competitors to enter the German market. And third, declining productivity might cause the government to intervene to protect important firms' existence or employment.[16] Using lagged values is not sufficient to control for these sources of bias, as firm productivity is persistent. Thus, lower firm productivity remains low even after it has caused increased import competition, which results in biased OLS estimates.

In our IV-2SLS strategy, we make use of the idea that the genuine competitiveness of German imports from a country-group n is reflected in the share of that country-group in the total imports of *third* countries, which is arguably unrelated to the competitiveness of domestic firms and other confound-

[14]In three NACE rev. 1.1 two-digit manufacturing industries, “Basic metals (27)”,”Machinery and equipment (29)” and “Transport equipment (35)”, the production function does not seem particularly well defined, with negative estimated output elasticities of capital. These industries are not considered in our further analysis.

[15]Table S1 in Appendix S3 provides summary statistics for our final sample.

[16]Prominent episodes during our period of analysis encompass the anti-dumping tariffs that the EU instigated against the Chinese solar industry to rescue the ailing East German solar industry or the partial state ownership and support of German car manufacturers.

ing factors specific to German firms (Autor et al., 2013; Dauth et al., 2014). Thus, we instrument our endogenous import competition measures (1) with the share of imports from country-group n in third countries' total imports:

$$IS_{it}^{n\rightarrow third} = \sum_{g}\left[\left(\frac{R_{igt}}{\sum_g R_{igt}}\right)\left(\frac{M_{igt}^{n\rightarrow third}}{M_{igt}^{World\rightarrow third}}\right)\right] * 100, \quad (10)$$

where $M_{gt}^{n\rightarrow third}$ is the value of third countries' imports of product g from country-group n, $M_{gt}^{World\rightarrow third}$ is the value of third countries' total imports of product g, and $R_{igt}/\sum_g R_{igt}$ is product g's share in total product market sales of each German firm.

A necessary condition for our IV-2SLS strategy to identify the effect of import competition is that the instrument in (10) captures only changes in the share of foreign firms on domestic markets in (1) which are neither directly nor indirectly related to the productivity of German firms (Autor et al., 2013; Goldsmith-Pinkham et al., 2020).

However, there might still be some threats to that strategy. First, $M_{gt}^{n\rightarrow third}/M_{gt}^{World\rightarrow third}$ might be related to ω_{it}. For instance, despite we use the competitiveness of a country-group n in third countries, there might be common shocks that Germany and the group of third countries in our instrument share. Similarly, there might be policies that favour domestic firms and weaken the position of foreign competitors on domestic markets as well as on markets of our third country group (e.g., policies at the EU level).

To cope with this issue, we define the instrument country group only in terms of countries that are unlikely to share these common shocks with Germany, while still being sufficiently similar to Germany, such that the instrument remains relevant. We follow the literature and only include countries in the instrument country group that are neither direct neighbours to Germany nor that share the same currency as Germany (Dauth et al., 2014). Specifically, we include Norway, New Zealand, Israel, Australia, Great Britain, Sweden, and Singapore, which all have a GDP per capita similar to Germany. We leave out several other high-income countries from the instrument group to define a sufficiently large group of non-European high-income countries (Section 2.2). A remaining concern is that there might be an independent effect of trade flows between the high−/low-income countries and our instrument group on German firms that would violate our exclusion restriction. In a robustness test, we therefore exclude Great Britain (Appendix S5.3), which is one of the main trading partners of Germany, from the instrument group. Using this specification, we find qualitatively similar results.[17]

Additionally, product shares in firms' portfolios, $R_{igt}/\sum_g R_{igt}$, could be itself a threat to the exogeneity of the instrument, if firms would adjust their product portfolio in anticipation of import competition. In our main specification, we use product portfolio weights in t.[18] However, in a robustness check, we also use a more rigorous specification with an instrument based on the constant product portfolio from the first observations year for every firm. For some firms this could be as early as 1995, while the period of analysis is 2000–2014. In this alternative instrument definition, the product portfolio does not change over time and within-firm variation comes solely from changes in the genuine competitiveness of the competitors.

[17]Also, other alternative definitions of our instrument country group do not qualitatively change our results.

[18]Recall that we use lags for the endogenous variable and the instrument.

4 | RESULTS

4.1 | Import competition and firm TFPQ

This section presents our results. We estimate equation (9) by OLS and IV-2SLS. As OLS might be subject to endogeneity issues, we base our interpretations on the IV-2SLS-results.

Table 3 reports the main results.[19] Regarding overall import competition (column 2), the IV-2SLS estimates imply that a 1% point increase in the foreign competitors' share is associated with an increase in domestic firms' productivity by 0.2 per cent.[20] The corresponding OLS estimate in column (1) is smaller in magnitude and statistically insignificant, which is consistent with a downward bias if import competition is particularly pronounced in markets where domestic firms are less competitive.

Distinguishing between import competition from high- and low-income countries indicates that only the former is positively associated with firm productivity gains. According to the IV-2SLS estimates in column (4), an increase in import competition from high-income countries by 1% point is associated with an increase in firm productivity by 1.1 per cent, whereas the effect of low-income country import competition is virtually zero.

To provide some intuition on the magnitude of this result, we consider the change in import-competition in our data (Figure 1). Average high-income import competition declined from 1.98 to 1.69 between 2001 and 2014. Using the estimates from Table 3, this implies that average firm productivity declined by $1.1^{*}0.29 = 0.32\%$ due to the change in high-income import competition during this period. This is roughly equivalent to one years's worth of German aggregate TFP growth during our sample period (Feenstra et al., 2015). Interestingly, our results imply that the increase in competition from low-wage countries was not associated with firm productivity gains.

Column (5) reports results of an IV-2SLS estimation, where we use a constant product portfolio from the first observation year of every firm to construct the instrument. This specification is more robust than the one in column (4), where we use information on firms' product portfolio in t for the instrument. If firms adjust their product mix in anticipation of import competition, using information from t might underestimate the true effect. Using constant product portfolios ensures that within-firm variation in the instrument comes only from changes in the genuine competitiveness of foreign firms. The corresponding estimate for the effect of high-income country import competition is positive and statistically significant, while that for low-income country import competition is still virtually zero and insignificant. Note that compared to column (4), the magnitude of the estimated effect for high-income import competition doubles, indicating that changes in firms' product portfolio might be an important adjustment margin for firms to escape competition. According to the point estimate in column (5), a 1% point increase in high-income country import competition increases firm productivity by 2.2 per cent.

Column (6) reports results from an IV-2SLS specification which only uses single-product firms that do not change the product they manufacture. This is an alternative specification to the one in column (5) as it completely shuts off product portfolio adjustments. Again, we find a positive and statistically significant estimate for import competition from high-income countries and no statistically significant

[19]The first stages of the IV-2SLS estimations are reported in Appendix S4.

[20]The magnitude of our coefficients is broadly in the range of estimates found in previous studies on the productivity effects of trade liberalisation. Amiti and Konings (2007) estimate that a fall in industry-level output tariffs in Indonesia by one percentage point is associated with an increase in firm productivity of 0.1 to 0.6 per cent. Topalova and Khandelwal (2011) find that one per cent reduction in industry-level output tariffs is associated with an increase in TFP of Indian firms by 0.05 per cent.

TABLE 3 Import competition and firm productivity – Main results.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	IV-2SLS (2nd stage)	OLS	IV-2SLS (2nd stage)	IV-2SLS (2nd stage)	IV-2SLS (2nd stage)	OLS	IV-2SLS (2nd stage)
	All firms	All firms	All firms	All firms	All firms, first portfolios	Single-product firms	Firms equally hit by both types of competition	Firms equally hit by both types of competition
$IC_{it-1}^{High+Low}$	−0.0001 (0.0005)	0.0018*** (0.0001)						
IC_{it-1}^{High}			0.0005 (0.0009)	0.0112*** (0.0036)	0.0225*** (0.0071)	0.0206** (0.0104)	0.0039** (0.0020)	0.0209*** (0.0059)
IC_{it-1}^{Low}			−0.0003 (0.0005)	−0.0005 (0.0010)	−0.0007 (0.0015)	0.0001 (0.0018)	−0.0004 (0.0006)	−0.0005 (0.0010)
Firm controls $_{it-1}$	YES	YES	YES	YES	YES	YES	YES	YES
First Portfolios	NO	NO	NO	NO	YES	NO	NO	NO
Single-product firms only	NO	NO	NO	NO	NO	YES	NO	NO
Firm-Industry FE	YES	YES	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	78,353	78,353	78,353	78,353	73,153	22,704	14,102	14,102
R^2	0.986	0.986	0.986	0.985	0.984	0.982	0.986	0.985
First-stage F-test	–	143.00	–	36.68	13.30	12.11	–	4.94
Number of firms	16, 911	16, 911	16,911	16,911	15,840	5461	3392	3392

Notes: This table reports the results from estimating equation (9) by OLS and by IV-2SLS (2nd stage; 1st stage results are reported in Table D.1 in online Appendix S4). All regressions include inverse probability weights. Included firm-level controls: export intensity (exports over sales) and number of products (not in column (6)). Columns (1) and (2) report results for total import competition. Columns (3) and (4) report results for import competition from high-income and low-income countries. Columns (2) and (4) construct instruments using product portfolio weights in t. Column (5) constructs instruments using constant product portfolio weights from the first observation year for every firm. In column (5), the number of observations drops due to changes in the product classifications which create difficulties in relating the first portfolio of a firm to current imports (e.g., mapping smartphone imports to 1995 product portfolios). Column (6) presents results for single-product firms. Columns (7) and (8) report results for firms that face simultaneously import competition from both types of competition and for which the exposure to one type is not larger than twice the exposure to the other. Standard errors are clustered at the firm level. Significance: *10 per cent, **5 per cent, ***1 per cent.

association between productivity and low-income country import competition. The point estimate in column (6) is comparable to the one in column (5) in which we used fixed product portfolios.

Columns (7) and (8) focus only on firms that simultaneously face both types of import competition and for which the exposure to one type is not larger than twice the exposure to the other. This specification rules out that the different reactions to high- and low-income competition are due to different firms being hit by these different types of competition shocks. The results are qualitatively unchanged and corroborate our previous findings indicating that the effects are driven by the different properties of the types of competition, not by differences in affected firms.

Next, we analyse whether the previous findings are an artefact of import competition from high-income countries systematically threatening the most important products. The incentives of firms to improve productivity might be higher when core products are exposed to competition. At the same time, high-income country import competition threatens comparably capital- and technology-intensive products that tend to be among the core products of German firms. We therefore use the product-level information in the data and calculate import competition with respect to firms' core products (with the largest share in total sales) and non-core products (all others).[21]

Table 4 reports result from OLS and IV-2SLS estimations of the productivity effects of import competition with respect to core and non-core products. Columns (1) and (2) show the results for the effects of total import competition. Columns (3) and (4) distinguish between import competition from high- and low-income countries. In columns (2) and (4), instruments are constructed using the product portfolio compositions in t. Columns (5) and (6) rely on fixed product portfolio information.

The IV-2SLS estimates indicate a positive effect of import competition on firm TFPQ only if core products of domestic firms are threatened by foreign competitors from other high-income countries. We again do not find any evidence of low-income country import competition leading to increases in firms' TFPQ. Overall, Table 4 underlines the importance of the rank of products threatened within firms and the origin of competition in determining the productivity effects of import competition.

In Appendices S5.1 and S5.2, we test the robustness of our result to different specifications of the groups of countries we use for our endogenous competition variables. We show that neither a more encompassing specification including additional European high-income countries nor a parsimonious specification only using the US, Canada, and China as trade partners changes our qualitative result that firm productivity only increases in response to high-income import competition.

4.2 | Import competition and other firm adjustments

To better understand the mechanisms behind our previous results, we study the effects of import competition on various firm adjustments in Table 5 (we focus on IV-2SLS results). Column (1) reports how firms adjust their prices. Although high-income import competition causes price to decline, we find no evidence of any relationship between low-income import competition and firm prices. Column (2) shows that firms' physical output increases in response to high-income country competition, while it declines in response to low-income import competition.[22] This is consistent with the price effects in Column (1). German firms engage in price competition with foreign competitors

[21]Multiproduct firms account, on average, for about two-thirds of their total sales with one distinct product. If we include also single-product firms, this figure raises to about three-fourths (see Appendix S3: Figure S1).

[22]Firm sales are deflated with a firm-specific (price) deflator, which allows us to interpret sales as quasi-physical output.

TABLE 4 Import competition and firm productivity – Core and non-core products.

	(1) OLS	(2) IV-2SLS (2nd stage)	(3) OLS	(4) IV-2SLS (2nd stage)	(5) IV-2SLS (2nd stage)	(6) IV-2SLS (2nd stage)
$IC\_Core_{it-1}^{High+Low}$	0.0001 (0.0004)	0.0009 (0.0007)			0.0014 (0.0042)	
$IC\_nonCore_{it-1}^{High+Low}$	−0.0006 (0.0005)	0.0001 (0.0011)			−0.0007 (0.0046)	
$IC\_Core_{it-1}^{High}$			−0.0000 (0.0009)	0.0065*** (0.0025)		0.0170* (0.0010)
$IC\_nonCore_{it-1}^{High}$			−0.0007 (0.0013)	0.0025 (0.0030)		−0.0103 (0.0070)
$IC\_Core_{it-1}^{Low}$			0.0002 (0.0005)	−0.0007 (0.0009)		−0.0060 (0.0071)
$IC\_nonCore_{it-1}^{Low}$			−0.0006 (0.0005)	−0.0003 (0.0013)		0.0089 (0.0073)
Firm controls $_{it-1}$	YES	YES	YES	YES	YES	YES
First Portfolios	NO	NO	NO	NO	YES	YES
Firm-Industry FE	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES
Observations	53,690	53,690	53,690	53,690	45,523	45,523
R^2	0.987	0.987	0.987	0.987	0.986	0.983
First-stage F-test	–	128.7	–	19.47	6.53	3.19
Number of firms	11,449	11,449	11,449	11,449	9682	9682

Notes: This table reports the results from estimating equation (9) by OLS and by IV-2SLS using separate import competition measures for core and non-core products. All regressions include inverse probability weights. Included firm-level controls: export intensity (exports over sales) and number of products. Columns (1) and (2) report results for total import competition. Columns (3) and (4) report results for import competition from high- and low-income countries. Columns (2) and (4) construct instruments using product portfolio weights in t. Columns (5) and (6) construct instruments using constant product portfolio weights from the first observation year for every firm. In columns (5) and 6, the number of observations drops due to changes in the product classifications which create difficulties in relating the first portfolio of a firm to current imports (e.g., mapping smartphone imports to 1995 product portfolios). Standard errors are clustered at the firm level. Significance: *10 per cent, **5 per cent, ***1 per cent.

from other high-income countries, presumably because production cost gaps are sufficiently small. In contrast, German firms seem to be unable to compete in terms of prices with low-wage competitors, due to production costs being on a much lower level in low-wage countries. As a result, German firms' market shares and output decline.

Columns (3)–(5) show how firms adjust their production inputs. Both types of import competition lead to a reduction in labour (despite not statistically significant for high-income country competition), capital, and intermediate inputs. Remarkably, however, German firms *increase* their physical output despite decreasing their inputs in response to import competition from high-income countries, explaining the positive productivity effect documented in the previous section. We further discuss this below. Column (6) reports a negative effect on the wage bill in response to both types of import competition, which is consistent with a decline in labour inputs. Finally, column (7) finds a small reduction in R&D expenditures in response to competition from low-income countries. Despite firms

TABLE 5 Import competition and firm adjustments.

	(1) Firm price index	(2) Output, log	(3) Employment (FTE), log	(4) Capital stock, log	(5) Intermediate inputs, log	(6) Wage bill, log	(7) R&D Expenditures in thousand €
IC_{it-1}^{High}	−0.0064*	0.0127*	−0.0053	−0.0098*	−0.0129*	−0.0104***	206.88
	(0.0035)	(0.0068)	(0.0041)	(0.0059)	(0.0072)	(0.0047)	(318.07)
IC_{it-1}^{Low}	0.0008	−0.0060***	−0.0031**	−0.0029**	−0.0062***	−0.0044***	−69.38*
	(0.0011)	(0.0021)	(0.0014)	(0.0015)	(0.0022)	(0.0015)	(37.12)
Firm controls $_{it-1}$	YES	YES	YES	YES	YES	YES	YES
Firm * Industry FE	YES	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES	YES
Observations	78,353	78,353	78,353	78,353	78,353	78,353	78,353
Number of firms	16,911	16,911	16,911	16,911	16,911	16,911	16,911
R^2	0.987	0.987	0.985	0.992	0.986	0.988	0.958
First-stage F-test	36.68	36.68	36.68	36.68	36.68	36.68	36.68

Notes: This table reports the second-stage results of IV-2SLS estimations using our specification in equation (9) with different dependent variables. The dependent variables in columns (1)–(7) are, respectively, firms' logged output price index, logged quasi-quantities, logged employment, logged deflated capital stock, logged deflated intermediate input expenditures, logged deflated wage bill, and deflated R&D expenditures. All regressions are weighted using inverse probability weights and include controls for firm export intensity and number of products. Standard errors are clustered at the firm level. Significance: *10 per cent, **5 per cent, ***1 per cent.

reduce other inputs, there is, however, no statistically significant association between high-income import competition and formal R&D.[23]

How can we interpret these findings? Concerning competition from low-income countries, our findings depict a clear picture: German firms do not compete in terms of prices with competitors from low-wage countries, lose market shares, and shrink. As a result, there is no firm productivity effect from low-income competition.

High-income import competition increases firm productivity by forcing a more efficient use of production inputs that translates into a reduction in total input expenditures while increasing output quantities (although the latter is only statistically significant to the 10% level). This increased production is sold via lower output prices.

A natural question is why these productivity gains have not been realised already before the competition shock. Yet, such evidence is consistent with studies discussing the role of X-inefficiencies within firms (e.g., Leibenstein, 1966) and the literature that highlights that competition affects the quality of management, (e.g., Bloom et al., 2015; Schmidt, 1997). X-inefficiencies are often seen as a form of rent consumption by non-shareholders (Biggerstaff et al., 2017). If this is true, then fiercer competition increases the price of this consumption. Theoretically, as demand curves become flatter, minor differences in productivity can lead to significantly different profit outcomes. Consequently, tighter competition forces firms to monitor their production processes more strictly.[24] Although we cannot precisely measure such X-inefficiencies in the data, our result can be explained by a reduction in such inefficiencies induced by competition.

5 | CONCLUSIONS

This study analyses the impact of import competition on firm productivity. We use comprehensive firm-product-level data from German manufacturing (2000–2014), which contain information on prices and quantities of firms' products. Combining this information with product-level import data allows us to measure firm-specific import competition, which is usually infeasible with common industry-wide measures of import competition. Moreover, the product price information in our data allows us to derive a quantity-based productivity measure that is not confounded by firm-specific factors that influence prices (e.g., market power).

We identify the effects of import competition on firm productivity by estimating a linear panel model with firm fixed effects using an IV-2SLS approach. We document a positive effect of import competition on firm productivity, which is driven by import competition from high-income countries. Import competition from low-income countries has no statistically significant productivity effect. These findings are not an artefact of competition from different countries targeting systematically different firms and hold for a subsample of firms simultaneously hit by competition from both types of countries. Neither are these effects driven by high-income country imports systematically threatening core products of domestic firms. Rather, our findings can be attributed to differences in terms of

[23]Though R&D is measured in Euros, we assess the association between import competition and R&D by means of linear estimation techniques due to the presence of a large amount of firm dummies (i.e., firm-industry fixed effects) and two endogenous regressors that need to be instrumented (Cameron & Trivedi, 2013; Wooldridge, 2010).

[24]A related strand of the literature interprets X-inefficiencies as information frictions: In a large survey of manufacturing firms, Bloom and Van Reenen (2010) and Bloom et al. (2012) showed that managers systematically overestimate their own management practices. Loosing market shares to competitors from countries similar to Germany might disabuse managers of that notion leading them to reorganise their production processes.

"competitiveness gaps" between German and foreign firms, depending on whether foreign competitors are located in high- or low-wage countries.

Our findings show that the productivity-enhancing effect of high-income country import competition results from firms using less inputs to produce more output. Consumers benefit from the induced cost savings by paying lower output prices. We argue that the documented productivity gains can be explained if firms were initially not operating at their maximum efficiency level. There is compelling evidence that firms indeed exhibit sizeable slack which explains a large part of the observed productivity dispersion between firms (Bloom et al., 2012). Firms have been shown to be unproductive because they are unaware of better production techniques (Bloom et al., 2012), or because firms' managers might consume a part of their firm's profits as leisure (Biggerstaff et al., 2017). Theoretically, competition should exert pressure towards efficiency. Empirically, this has so far only been shown in highly specific cases (e.g., Bloom et al., 2015; Borenstein & Farrell, 2000). Our study complements the literature by providing large-scale cross-industry evidence showing that competition activates unexploited productivity reserves.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The database we use is called "AFiD – Amtliche Firmendaten für Deutschland" or, in English, "Official firm data for Germany (AFiD)". The data is supplied by the statistical offices of Germany via their so called "Forschungsdatenzentrum". This data constitutes the basis for all aggregate statistics on Germany published by the statistical offices of Germany and Eurostat. Relevant contact information and information on how to access the data can be found here: https://www.forschungsdatenzentrum.de/en/ (the German version of the website is, however, much more detailed). You can also physically access the data in various locations within Germany. We access the data at the statistical office of Sachsen-Anhalt: Statistisches Landesamt Sachsen-Anhalt, Merseburger Str. 2, 06110 Halle (Saale). Email: forschungsdatenzentrum@stala.mi.sachsen-anhalt.de. The data can only be accessed by researchers for research purposes. To access this data, researchers must fill in an application. Information on that can be found here: https://www.forschungsdatenzentrum.de/en. The program (do) files we used to produce the results are archived together with all intermediate datasets at the statistical office of Sachsen-Anhalt: Statistisches Landesamt Sachsen-Anhalt, Merseburger Str. 2, 06110 Halle (Saale). Interested researchers may contact us for details on the replication of our results.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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