The China Effect on Manufacturing Productivity in the United States and Other High-income Countries

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Abstract

From a macroeconomic perspective and using input-output techniques, this article investigates to what extent, and how, the growing use of Chinese intermediates has contributed to the labour productivity growth within the manufacturing production processes of 22 high-income countries. The main result — based on almost 400 global value chains during the period 2000-2014 — is that this productivity effect is significant and economically relevant. This is also the case for the United States. The effect holds before and after the financial crisis, is robust to different specifications, and is identified in almost all production processes. Three mechanisms behind the identified pattern are — tentatively — identified: reduced employment, reduced prices, and productivity enhancing functional specialization. However, China is not special: the absolute productivity effect of the growing use of Eastern European intermediates seems to be even larger. Finally, China and Eastern Europe are special in relation to the high-income countries: growing intra-trade of intermediates among the high-income countries is associated with weaker productivity growth.

The welfare effects of trade constitute a longstanding issue in economics. With China emerging as the factory of the world, this question has recently attracted renewed attention. A main aspect of this is how China's dominating role within global value chains (GVCs) affects high-income countries (HICs).[2] This article contributes to this literature by addressing the following main question: To what extent, and

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2 See Autor *et al.* (2013, 2015, 2019, 2020a, 2020b), Dauth, Findeisen, and Suedekum (2014), Acemoglu, Akcigit, and Kerr (2015), Bloom, Draca, and Van Reenen (2016), Feenstra, Ma, and Xu (2019), Pierce and Schott (2020), Jaravel and Sager (2020), Amiti *et al.* (2020), Che *et al.* (2020) and Bloom *et al.* (2021).

how, does the growing use of intermediate inputs (hereafter referred to as intermediates) imported from China affect the productivity growth in the manufacturing sector in the United States and other HICs? The approach is macro-oriented, in the sense that the units of study are countries and sectors.

Recent research on the effects of China on the labour markets in the HICs has shown that a credible answer to the main question requires a vertically integrated perspective.[3] This means that the manufacturing sector should not be treated as an isolated unit, but as a chain of activities that connect sectors and countries through the trade in intermediates. Therefore, the magnitude and character of the labour market effects of the Chinese trade shock are determined by the extent to which this network diffuses the initial effect to all sectors in the HICs.

This type of vertically integrated analysis requires the use of input-output (IO) techniques. Consequently, this article is related to the renewed macroeconomic interest in IO linkages. As argued by Acemoglu and Azar (2020), the association between IO linkages and productivity is an underresearched topic that deserves more attention. Addressing the main question from a vertically integrated perspective, this article represents an attempt to take some small steps in this direction.

The productivity measure used in this article is called vertical labour productivity and is defined as the ratio between the value added and employment generated within the domestic economy in order to produce a manufactured product. Accordingly, this measure includes all upstream/backward activities along the domestic supply chains needed to finalize the product.[4]

The article proceeds as follows. The first section positions the article within the related literatures and presents further questions to be answered, while answering the main question. Next follows a section presenting the main variables, the empirical approach, and some descriptive statistics. After this follows a section that discusses and tests the identification strategy. Next follows a section containing the empirical results, wherein three possible explanations for these results are discussed and empirically tested. The last section concludes and briefly discusses some avenues for future research.

Related Literatures

Global value chains and productivity diffusion

The starting point of this article is the

3 Autor, Dorn, and Hansen (2016), Pierce and Schott (2016), Acemoglu *et al.* (2016), Feenstra and Sasahara (2018), and Bloom *et al.* (2019). Autor and Salomons (2018) and Reijnders, Timmer, and Ye (2021) use the same argument for the employment effects caused by technical change.

4 With the argument that the emergence of the GVCs requires a new approach, similar productivity measures have recently been used in Timmer (2017), Gu and Yan (2017), Timmer and Ye (2018, 2020), Pahl and Timmer (2019) and Buckley *et al.* (2020). However, this approach to productivity analysis is not new. Based on the domestic economy, it is found in early IO research on the US economy (Leontief 1953; Carter 1970). It is also a common theme in the evolutionary tradition (Winter and Nelson, 1982; Rosenberg (1982) and in the post-Keynesian tradition (Pasinetti, 1981, 1993). Other examples of this type of productivity research are found in Wolff (1994), Dietzenbacher *et al.* (2000), De Juan and Febrero (2000), and Ten Raa and Wolff (2000, 2001, 2012).

emergence and increased complexity of the GVCs and how China has become a central node within the global production network, dominated by the trade in intermediates.[5] Using a production process perspective, with each production stage adding value to the final product, recent macroeconomic GVC research has focused on how shocks, such as the China shock, are spread around the world through the trade in intermediates.[6] Within this framework, the manufacturing firm decides how much and from where they buy their intermediates. Optimally, the firm should base its decision on the vertically integrated labour productivity adjusted cost-minimization (Antras and de Gortari, 2020). Empirically, the microeconomic GVC research shows, among many other things, that importing firms often have access to more input varieties and use higher quality intermediates.

Along similar lines, the trade in intermediates is at the centre stage in the recent research that endogenizes the IO structure and how it changes over time (Acemoglu and Azar, 2020).[7] When firms cost-minimize their use of intermediates, new input combinations will emerge, due to technical change. If this new combination leads to price reductions, a small change in one sector can cause a major change in the organization of production and affect productivity in many sectors. This diffusion aspect of the trade in intermediates is also considered in the recent research on shock propagation and how it may affect the macroeconomic volatility (Acemoglu *et al.*, 2012, 2015; Acemoglu, Ozdaglar and Tahbaz-Salehi, 2016; Carvalho and Tahbaz-Salehi, 2019). This occurs when some sectors are particularly important as suppliers and when the use of the intermediate is widespread. The empirical analysis in Acemoglu, Akcigit, and Kerr (2015), focusing on US IO tables for 1992, shows that productivity shocks propagate downstream, and their conclusion is that this amplification mechanism is more important than what is typically presumed in the macroeconomic literature. Moreover, the indirect productivity effects, occurring along the supply chains, are quantitatively more important than the productivity effect in the sector that was first hit by the shock.

The China shock

Naturally, another related literature focuses on the question: how do imports from China affect HICs? As mentioned, one insight from this research is that the labour market effects caused by the China shock — driven by domestic reforms, trade liberalizations and new ICT uses — cannot

5 For general overviews of the emergence and consequences of the GVCs, see Baldwin (2016, 2017, 2019), Ponte, Gereffi, and Raj-Reichart (2019), IMF (2019), WTO (2019) and World Bank (2020).

6 Antras and Chor (2021) is a recent survey of this GVC research. On the theoretical side, recent contributions are Caliendo and Parro (2015), Caliendo, Parro, and Tsyvinski (2017), Antras and Chor (2019) and Antras and de Gortari (2020). These frameworks have also been used in counterfactual exercises to quantity the effects of US-China trade tensions (e.g. Caceres, Cerdiero, and Mano, 2019; Ju *et al.*, 2019), productivity shocks in the US economy when IO linkages are present (Caliendo *et al.*, 2019), effects on the US economy from the China trade shock (Caliendo *et al.*, 2019; Rodriguez-Clare, Ulate, and Vasquez, 2020) and the effect of global specialization on the sensitivity for productivity shocks in other countries (Caselli *et al.*, 2020).

7 See also Carvalho and Voigtländer (2015) and Oberfield (2018).

be properly identified by only focusing on the manufacturing sector itself. This approach was used in the seminal analysis of Autor, Dorn, and Hansen (2013), but the whole manufacturing process, including the supply chains, was included in Acemoglu *et al.* (2016). This production process perspective can create both positive and negative employment effects, indicating that the net effect of the Chinese trade shock is ambiguous in sign. The empirical analysis in Acemoglu *et al.* shows that the negative employment effect of this fundamental change in the global economy is more than doubled, as compared to the effect within the manufacturing sector itself. The authors conclude: "Thus, interindustry linkages magnify the employment effects from trade shocks...." (Acemoglu *et al.*, 2016:145). Although the level and sign of this employment effect is still discussed, the standard approach in the macroeconomic literature on the China shock has become to apply a vertically integrated perspective, in the sense that the IO structure is included in the empirical analysis on the effects of China on the labour markets in the HICs.[8]

To the best of my knowledge, no attempt has been made to study the macroeconomic effects of China's intermediate exports on the productivity within the manufacturing production processes among the HICs, i.e. when the productivity among the suppliers are included in the analysis. There are, however, some related research. From a microeconomic perspective, Bloom, Draca, and Van Reenen (2016) investigate the productivity aspect of the China shock. Their main conclusion is that the effect is positive on firm TFP growth in four European countries between 1996-2007. Using instrumental techniques, they find that 30-60 per cent of the TFP growth between 2000-2007 was accounted for by the imports from China. Bloom *et al.* (2021) continue along a similar path, and show that firms in 11 European countries that are more exposed to trade from China increased their productivity-enhancing efforts more than other firms between 1995-2005, while also experiencing a decline in sales. From a propagation perspective, Acemoglu, Akcigit, and Kerr (2015) use the IO structure for the year 1992 to investigate how different types of shocks are spread to almost 400 sectors in the US economy and how they affect value added, employment, and labour productivity. In terms of a trade shock from China, labour productivity is unaffected, since the effects on value added and employment are both negative and of a similar magnitude.

Productivity in an IO setting

From a general IO perspective, Acemoglu and Azar (2020) investigate how changes in individual cells of the Leontief inverse affect TFP. They find that "large" changes — defined as being above the 20th percentile in terms of changes in the number of suppliers — in the composition of intermediates contribute to faster productivity growth in the United States. Over the

8 Autor, Dorn, and Hansen (2016:220) express this in the following way: "A full account of the impact of trade shocks thus requires incorporating input-output linkages between domestic industries." See also Pierce and Schott (2016), Bloom, Draca, and Van Reenen (2016), and Feenstra and Sasahara (2018).

period 1987-2007, between 40-60 per cent of the difference in TFP growth between sectors can be explained by these changes in the intermediate structure.[9] From a GVC perspective, and using vertically integrated productivity measures, one main conclusion in Timmer (2017) and Timmer and Ye (2018, 2020) is that a substantial part of the TFP growth within the manufacturing production process of a group of HICs since the 1990s is generated outside the manufacturing sector itself.

Gu and Yan (2017) follow the same approach. Among a group of HICs during the period 1995-2007, their main result is that there is a substantial difference between the conventional, sectoral-based TFP growth and the TFP measure that includes the supply chains. Moreover, due to imported intermediates produced by industries with high productivity levels, Canada has experienced more rapid productivity growth than EU countries and the United States from participating in the GVCs. Pahl and Timmer (2019) define their vertically integrated labour productivity measure as the ratio between the value added and employment used to produce an exported manufactured product. Based on 58 countries and the period 1970-2008, their main result is that a high level of imported intermediates correlates with a faster vertical labour productivity growth. This result does not, however, seems to hold for the most productive countries.

Questions addressed

Based on the aforementioned literatures, this article investigates the impact of the China shock on the vertical labour productivity within the manufacturing production processes of 22 HICs. The macroeconomic approach has two main advantages. First, it gives overall estimates and establishes the general picture of the productivity effect among close to 400 GVCs of the HICs. These aggregate estimates can, in turn, be broken down into analyses of separate countries and GVCs. Second, it makes it possible to fully exploit the vertical dimension of manufacturing production (Antras and Chor, 2021), i.e. how firms in different sectors and countries interact in order to finalize a product and how this affects productivity outcomes.

While trying to give a credible answer to the main question, and following some of the paths in the China shock literature, this article also addresses the following questions:

1. Is there a China effect on value added or employment – or both?
2. Is there a China effect on prices?
3. Is there a productivity enhancing China effect on the allocation of manufacturing activities performed in different countries?
4. In a comparison with Eastern Europe, are China's intermediates a special case?

9 In a non-competitive (bargaining) framework, see Acemoglu *et al.* (2020) for a further theoretical discussion on how a TFP shock may affect the affected sector's suppliers and customers.

Descriptive Statistics and Empirical Model

Data

The source of data in this article is the World Input-Output Database (WIOD). This type of database has recently emerged through the harmonization of national accounts statistics and trade statistics, and it contains intermediate trade between countries/sectors. Therefore, this dataset has become a necessity in current macro-oriented GVC research (Antras and Chor, 2021).[10] The WIOD covers 43 countries, contains data for the period 2000-2014 and covers 56 sectors, of which 19 are defined as manufacturing sub-sectors.[11] Following the argument and method in Timmer *et al.* (2021), the variables used in this article are expressed in constant prices with base year=2000. Translation into a common currency (USD) is done by market exchange rates.[12] Employment is defined as the number of persons engaged.

Sectors are classified according to the ISIC Rev. 4 and the IO tables follow the 2008 version of the System of National Accounts (SNA).[13] Each manufacturing sub-sector in each country, including its domestic supply chain, will be viewed as a separate GVC (Antras and Chor, 2019; Pahl and Timmer, 2019). With 22 HICs and 19 manufacturing sub-sectors in each country, 418 GVCs, at most, will be included in the empirical analysis. The HICs are EU15 before the 2004 enlargement, Canada, United States, Switzerland, Norway, Australia, Japan, and South Korea.

Variables

The variables used in this article are constructed using IO techniques and the Leontief inverse matrix.[14] By pre- and/or post-multiplication, this matrix is used to create variables that include the upstream/backward activities needed along the supply chains to produce a final product. Therefore, each GVC represents a "composite" sector, as if all production stages were totally vertically integrated.

For each manufacturing production process in each country — i.e. for each GVC — the main variables are the following:[15]

10 For this article, one particularly relevant assumption underlying databases such as the WIOD is that China's intermediates are produced with the same technology regardless to where they are exported.

11 The values of intermediates and final demand in a WIOT can be viewed as endogenous variables, in the sense that they are the result of firm-level decisions on how they optimize the production process (Antras and Chor, 2021).

12 The exact procedure for expressing variables in constant prices in a common currency is as follows. First, the WIOD-researchers use the market exchange rates to convert the national (nominal) values to USD values. Second, they construct time series in t-1 prices (in constant USD). These two datasets (nominal values and t-1 values expressed in USD) are officially released on the WIOD homepage. The third step is to covert these two data sets into time series expressed in constant prices with a base year. This is done in Timmer *et al.* (2021) and this is the procedure followed in this article. To do this, the real growth rate for each particular year (in this case between 2000 and 2001) is equal to ln(value in previous year's prices in 2001/value in current prices in 2000). Starting with the year 2000, these real growth rates are, in the next step, used to calculate the value-added level in constant prices with base year 2000 for each of the years 2001-14.

13 For further details about WIOD, see Dietzenbacher *et al.* (2013) and Timmer *et al.* (2015).

14 See Miller and Blair (2009) for the fundamental ideas behind the IO analysis.

15 See Appendix for further details and the construction of the variables.

Vertical labour productivity: the ratio between the (vertical) value added and (vertical) employment needed to satisfy final demand, including all upstream stages of the domestic production process.

Output multiplier: the gross output needed in the domestic economy in order to produce one unit of final demand, including all upstream stages of the domestic production process.[16]

Import multiplier: the use of imported intermediates per unit of final demand, including all upstream stages of the domestic production process.[17]

Import multiplier from China: the use of imported Chinese intermediates per unit of final demand, including all upstream stages of the domestic production process.

Overall multiplier: the gross output needed to produce one unit of final demand, irrespective of whether the intermediates are domestically or foreign sourced. This variable, constructed by the author, is defined as the sum of the output and import multiplier.

Capital multiplier: the domestic use of the capital stock per unit of final demand, including all upstream stages of the domestic production process.

Vertical gross output: the gross output needed to satisfy final demand, including all upstream stages of the domestic production process.

Descriptive statistics

Table 1 summarizes how the main variables have developed between 2000-2014. Some conclusions emerge. First, with more than a five-fold increase in its absolute level, China's productivity convergence is substantial. Second, the import multiplier has increased over the whole period in both the HICs and the United States, while it has decreased in China after the financial crisis, suggesting a growing self-sufficiency. With only minor changes in the output multiplier, the growing import multiplier in the HICs and the United States implies that the relative use of imported intermediates has grown. Third, the relative use of Chinese intermediates in the HICs and the United States has increased substantially. In absolute terms, the use of Chinese intermediates increased by 420 per cent among the HICs: from 0.0037 in 2000 to 0.0192 in 2014. In the United States, the increase was 490 per cent: from 0.0030 to 0.0178. Following the reduced absolute Chinese import multiplier since the financial crisis, the Chinese use of imported intermediates from the HICs and the United States has been reduced in absolute terms. Finally, China's productivity convergence has occurred alongside a considerable decrease in the capital multiplier, indicating a strong growth in the capital productivity, i.e. less capital is needed to produce one unit of final demand.

Empirical model

Following much of the recent research on the China shock, a linear panel model

16 This variable can be seen as the domestic counterpart to the measure of upstreamness in recent GVC research (Antras and Chor, 2019).

17 This variable is similar to the measures of vertical specialization in the recent GVC research.

Table 1: Descriptive Statistics

Variable	2000	2008	2014
High-income Countries			
Vertical labour productivity level (1000s, USD)	52.8	94.7	104.5
Output multiplier	1.72	1.72	1.68
Import multiplier	0.29	0.32	0.35
Overall multiplier (output + import multiplier)	2.01	2.04	2.03
Import multiplier from China	0.0037	0.0129	0.0192
Import multiplier/Output multiplier	0.17	0.19	0.21
Import multiplier from China/Import multiplier	0.013	0.040	0.055
Capital multiplier	1.30	1.05	1.12
United States			
Vertical labour productivity level (1000s, USD)	70.9	109.3	127.5
Output multiplier	1.80	1.79	1.81
Import multiplier	0.21	0.23	0.24
Overall multiplier (output + import multiplier)	2.02	2.02	2.05
Import multiplier from China	0.0030	0.0109	0.0178
Import multiplier/Output multiplier	0.12	0.13	0.14
Import multiplier from China/Import multiplier	0.014	0.047	0.074
Capital multiplier	1.17	0.96	0.92
China			
Vertical labour productivity level (1000s, USD)	2.7	7.5	15.0
Productivity convergence: HIC (share)	0.05	0.08	0.14
Productivity convergence: US (share)	0.04	0.07	0.12
Output multiplier	2.55	2.62	2.96
Import multiplier	0.15	0.20	0.16
Overall multiplier (output + import multiplier)	2.70	2.82	3.12
Import multiplier from HIC	0.060	0.067	0.056
Import multiplier from US	0.006	0.009	0.006
Import multiplier/Output multiplier	0.059	0.076	0.054
Import multiplier from HIC/Import multiplier	0.40	0.34	0.35
Import multiplier from US/Import multiplier	0.04	0.05	0.04
Capital multiplier	1.54	0.53	0.31

Note: The estimates for the HICs are unweighted averages among the 22 HICs and 19 manufacturing sub-sectors in each country, including all upstream/backward stages of their domestic supply chains (i.e., 418 GVCs). The variables are measured in constant prices with base year=2000. The multiplier variables should be interpreted as: a unit change in final demand generates xx units of the variable in question within the domestic economy, including all upstream/backward stages of the domestic supply chains.

with a fixed effect estimator will be used to empirically analyze the causal effect of the growth in the use of Chinese intermediates on the vertical labour productivity growth within the GVCs of the HICs. Accordingly, the following equation will be the empirical backbone of the article:

$$VLP_{ijt} = \beta_1 X_{1,ijt} + \beta_k X_{k,ijt} + \alpha_i + \varepsilon_{ijt} \quad (1)$$

where VLP_{ijt} is the vertical labour productivity level in GVC i in country j at time t. β_1 is the main coefficient, indicating the average effect of the change in the use of Chinese intermediates on the change in vertical productivity. The β_k vector contains different coefficients depending on which control variables are included in the particular specification, α_i is the GVC-specific intercept and controls for the time-invariant differences between the GVCs that are not included in the regression. ε_{ijt} is the "usual" disturbance, which varies between GVCs and over time.

Identification

General approach

How can it be made likely that any correlation between the growing use of Chi-

nese intermediates and the vertical labour productivity growth can be interpreted in causal terms? In this article, this ever-existing endogeneity problem is addressed using China's vertical labour productivity as the instrumental variable. The support for this choice is found in recent research on the effects of Chinese imports on the HICs. The argument for the IV strategy used in this research is that the effect of China — the China shock — is supply-driven, in the sense that it is mainly caused by political and economic reforms within China.[18] The empirical foundation of this strategy is centred around China's strong productivity growth caused by the reforms (supported by the data in Table 1).[19] This, in turn, has increased HICs' intermediate and final imports from China. More precisely, to solve the endogeneity problem in this setting, the instrumental variable has been the imports from China among HICs not included in the particular study.[20]

Following the same line of reasoning but using China's vertical labour productivity as the instrumental variable has two main advantages. First, China's strong productivity growth represents the core aspect of the supply-argument. Therefore, the chosen strategy opens up for a strong causal interpretation of China's effect on the HICs. Second, the chosen methodology makes it possible to empirically test the exclusion criterion.[21]

Exclusion criterion

Apart from a strong first-stage correlation, the second criterion for being an appropriate IV strategy is that the chosen instrumental variable satisfies the exclusion criterion. This criterion is met if it is reasonable to believe that the use of Chinese intermediates is a main and independent channel through which China's strong vertical labour productivity growth affects the vertical labour productivity growth in the HICs. From a theoretical perspective, this connection is central in a world of GVCs, and particularly so when it comes to China emerging as the factory of the world (Antras and Chor, 2021). To test the exclusion criterion empirically, however, the following question is addressed: is there a positive causal effect from the growth of HICs' import multiplier from China on the vertical labour productivity growth in the HICs, when controlling for China's vertical labour productivity? If this is the case, the import multiplier from China has an independent effect on the productivity growth in the HICs. Table 2 presents the answer to this question.

Using the linear panel data model with the fixed effect estimator presented in equa-

18 After the seminal work by Autor, Dorn, and Hansen (2013), this strategy is often used. Many of the articles already mentioned use some variety of it. See also Antras *et al.* (2017), Acemoglu and Restrepo (2019), Constantinescu, Mattoo, and Ruta (2019), Acemoglu and Azar (2020), and Bloom *et al.* (2021).

19 As an example of this, Antras *et al.* (2017) model the China shock as a productivity increase in the Chinese production of intermediates.

20 For example, when studying the China effect on the US economy, imports from China among a number of — often eight — other HICs are used as the instrument.

21 As will be clear in the main estimations to come, as an instrumental variable China's vertical labour productivity generates highly significant first-stage correlations.

Table 2: Test of the Exclusion Criterion

High-income countries				
Dependent variable: vertical labour productivity	Only Chinese productivity	IV. Including the use of Chinese intermediates	IV. Including the use of Chinese intermediates, lag 1	IV. Including the use of Chinese intermediates, lag 2
China's vertical labour productivity	0.335***	0.02	0.067	0.13
	(0.049)	(0.078)	(0.091)	(0.098)
HICs' import multiplier from China		0.334***	0.394***	0.394***
		(0.065)	(0.072)	(0.076)
Instrument	No	Yes	Yes	Yes
R^2 - within	0.86	0.93	0.90	0.85
N	268	268	250	232

Note: Linear fixed effect IV estimations (2SLS). Other included regressors are: output multiplier, import multiplier, and vertical gross output. Vertical gross output is used to control for the actual level of production, or more precisely: the change in the level of gross output needed to satisfy final demand. All variables except China´s vertical labour productivity is measured by their unweighted average. Years: 2000-2014. Log values. *** = p<0.001. The variables are expressed in constant prices with base year=2000. Since China lacks productivity data for the manufacturing sub-sector Repair and installation of machinery and equipment (C33), robust standard errors in parentheses are adjusted for 18 clusters (manufacturing sub-sectors, including their domestic supply chains). Since China´s vertical labour productivity is a variable on its own in the estimations, and analogously with much of the recent China shock literature, the instrumental variable is the import multiplier from China among the 21 countries in the WIOD not defined as a HIC. In the 2SLS estimation without lag, the F-value of the first-stage regression is 1856 and the elasticity of the instrumental variable is significant at p<0.001 (the F-value should not be lower than 10-15 in order for the IV strategy to be appropriate). The results for the United States are similar to those of the HICs, although China´s vertical labour productivity also seems to have an independent, significant positive elasticity in the 2SLS estimations.

tion (1), and including three regressors — the output and import multiplier controlling for the overall network of intermediate use, and vertical gross output controlling for the actual level of demand — the first column shows that there is a positive and significant correlation between China's productivity growth and HIC productivity growth, indicating a process of diffusion. Then, what happens to this correlation when HICs' import multiplier from China is included in the estimation? Column 2 shows two effects. First, the significant elasticity of China's productivity from the previous estimation disappears. Second, the elasticity of the import multiplier from China turns out to be significant and economically relevant.

This indicates that there is no causal link between China's and HIC productivity growth when the import multiplier from China is unchanged. And the other way around, when China's productivity is held constant, there is still a significant positive effect of HIC use of Chinese intermediates on HIC productivity growth. Using lags, the remaining two columns strengthen this result.[22] Therefore, the growing use of Chinese intermediates seems to be necessary to establish a causal link between China's strong productivity growth and HIC productivity growth. From my viewpoint, these estimations thus give credible empirical support for the argument that the growing use of Chinese intermediates, at least, represents an independent and main channel for the productivity diffusion from China to the HICs. Accordingly, China's vertical labour productivity should qualify as an appropriate instrumental variable within the setting of this article.

22 The fact that the elasticities with lags 1-2 are larger than the elasticity with no lag, indicates the importance of using lags when analysing the productivity effect of Chinese intermediates.

Table 3: Baseline Estimations for Vertical Labour Productivity

Panel A: High-income Countries

Dependent variable: vertical labour productivity	Without Chinese intermediates	With Chinese intermediates	IV: with Chinese intermediates	IV: Chinese intermediates and the overall multiplier	IV: Chinese intermediates and the capital multiplier
Output multiplier	-1.989***	-1.466***	-0.951***		-0.496*
	(0.214)	(0.174)	(0.203)		(0.224)
Import multiplier	0.690***	-0.138	-0.823***		-0.868***
	(0.059)	(0.075)	(0.088)		(0.087)
Import multiplier from China		0.320***	0.587***	0.476***	0.564***
		(0.018)	(0.026)	(0.016)	(0.026)
Overall multiplier				-1.769***	
				(0.231)	
Capital multiplier					-0.350***
					(0.077)
Instrument	No	No	Yes	Yes	Yes
R^2 - within	0.31	0.61	0.40	0.51	0.46
N	5866	5866	5560	5560	5560

Panel B: United States

Dependent variable: vertical labour productivity	Without Chinese intermediate	With Chinese intermediates	IV: with Chinese intermediate	IV: Chinese intermediates and the overall multiplier	IV: Chinese intermediates and the capital multiplier
Output multiplier	-3.459***	–2.004***	-1.089*		-1.041
	(0.353)	(0.341)	(0.553)		(0.614)
Import multiplier	0.949***	0.135	-0.304		-0.303
	(0.121)	(0.165)	(0.209)		(0.204)
Import multiplier from China		0.234***	0.376***	0.334***	0.372***
		(0.031)	(0.061)	(0.025)	(0.061)
Overall multiplier				-1.526***	
				(0.338)	
Capital multiplier					-0.036
					(0.105)
Instrument	No	No	Yes	Yes	Yes
R^2 - within	0.74	0.85	0.83	0.84	0.83
N	283	283	266	266	266

Note: Linear fixed effect IV estimations (2SLS). Robust standard errors in parentheses, in the HIC estimations (US) adjusted for 408 (GVCs, i.e., countries*manufacturing sub-sectors, including their domestic supply chains) (19) clusters (GVCs, i.e., manufacturing sub-sectors, including their domestic supply chains) when no instrumental variable is used, and adjusted for 390 (18) clusters in the IV estimations. The variables are expressed in constant prices with base year=2000. The instrumental variable is China's vertical labour productivity. Vertical gross output is used to control for the actual level of production, or more precisely: the change in the level of gross output needed to satisfy final demand. Years: 2000-2014. Log values. $^{***}p < 0.001$,$^{**}p < 0.01$,$^{*}p < 0.05$. In column 3, the F-value of the first-stage regression for the HICs (US) is 321 (175), and the instrumental variable is significant at $p < 0.001$.

Results

Benchmark estimations

To what extent, and how, does the growing use of Chinese intermediates affect the vertical labour productivity growth within the manufacturing production processes of the United States and other HICs? To find a credible answer to this main question, the first steps are taken in Table 3. Using the linear panel data model with a fixed effect estimator, in the first column, the HICs'/United States' productivity is – apart from the control for the business cycle – only regressed against the two variables that describe the overall network of intermediate trade: the output and the import multiplier, respectively. The results for the HICs and the United States are very similar. When keeping the output multiplier (import multiplier) constant, a growing use of imported (domestic) intermediates is positively (negatively) and significantly correlated with a faster productivity growth. This estimation thus suggests that a growing use of imported intermedi-

ates per unit of final demand — the core aspect of the new global economy dominated by the GVCs — has been rewarding in terms of productivity growth.[23] On the other hand, an increased domestic specialization in terms of intermediate use per unit of final demand correlates negatively with the productivity growth, when controlling for the import multiplier.[24]

What happens to the import multiplier when the import multiplier from China is included in the estimation? Column 2 shows that the positive elasticity of the import multiplier disappears, both for the HICs and the United States. Instead, the elasticity of the import multiplier from China becomes positively significant. Consequently, when the import multiplier from China is held constant, there is no positive correlation between the growing use of imported intermediates and a faster productivity growth. This is a first indication that the positive productivity contribution from the growing use of foreign intermediates among the HICs seems to be particularly associated with Chinese intermediates.

The next question is: what happens to the elasticities in Column 2 when the IV strategy is applied? First, Column 3 shows that the elasticity of the import multiplier from China is considerably increased in both the HICs and the United States, to 0.587 and 0.376, respectively, indicating that an appropriate IV strategy is important when investigating the size of the causal effect of the China shock on the productivity in the HICs. A 1 per cent increase in the use of Chinese intermediates per unit on final demand thus, on average, leads to a 0.587 (0.376) per cent increase in the growth of the vertical labour productivity in the HICs (United States).[25] Second, the elasticity of the import multiplier turns significantly negative in the HICs, further emphasizing the role of China in the vertical specialisation of the global economy. Third, the explanatory power of this benchmark results in terms of R^2 is particularly large in the United States: more than 80 per cent of the difference in productivity growth between its manufacturing sub-sectors is explained by the estimated model.

However, is the result in Column 3 dependent on how the overall network of intermediates is defined? Substituting the output and import multiplier for the overall multiplier, Column 4 shows that this somewhat reduces the elasticity of the use of Chinese intermediates in both the HICs and the United States, but it is still significant at $p < 0.001$. Another obvious concern is possible omitted variables. Follow-

23 For the HICs, the correlation between the output multiplier and the import multiplier is –0.58. Clearly, to a certain extent the use of domestic intermediates is low when the use of imported intermediates is high – and vice versa. However, between 2000-2014 the mean value of the overall multiplier spans from 1.19 to 3.31, indicating substantial differences between the GVCs in the amounts of intermediates used per unit of final demand.

24 One reason for this somewhat counterintuitive result may be that the yearly changes in the output multiplier are so small that they do not have the strength to counterbalance other forces around. Also, when lags are added this negative elasticity disappears. See Table 4.

25 When applying weighted estimations these results are confirmed. This is also the case when another IV strategy is used, analogously constructed from the recent China shock literature. For further details, see the Appendix.

ing the main question in this article, an important issue is related to the exclusion of the capital stock.[26] Therefore, the estimation in the last column includes the capital multiplier. As can be seen, its elasticity turns out to be significant in the HICs but insignificant in the United States. The negative significance means that in GVCs with a faster reduction in the capital multiplier — i.e. when the use of capital per unit of final demand decreases rapidly — the vertical labour productivity grows even faster. Hence, a more efficient use of the capital stock leads, in line with theory, to faster vertical labour productivity growth. In the United States, the non-significant elasticity of the capital multiplier suggests that its vertical labour productivity growth has been more dependent on TFP growth.[27]

Separate time periods and lag structures

With a vertically integrated perspective and its focus on the process of diffusion within and between countries, it is very reasonable to add lags to the analysis.[28] There are three main reasons for this. First, it reduces the potential problem of reversed causality. Second, it is theoretically reasonable to believe that the productivity effect of the use of Chinese intermediates is not instantaneous: that the (strongest) effect does not necessarily show up in the same year as the transaction is registered. Finally, the results presented in Table 2 indicated the existence of such delayed effects.

Therefore, the question to be answered in this section is: when adding lags to the main estimation in Column 3 in Table 3, how persistent is the productivity effect of the growing use of Chinese intermediates? But first, is there any difference in the China effect before and after the financial crisis? Columns 1-2 in Table 4 give a clear answer: the productivity effect is positively significant in both periods in both the HICs and the United States. For the HICs, the size of the effect is larger before the financial crisis, while the opposite is the case in the United States. A common pattern between the two is, however, that the explanatory power of the estimated model is lower after the financial crisis, indicating that differences in productivity growth rates between GVCs are less dependent on the variables included in the estimation. Moreover, the F-value of the first-stage regression is considerably lower after the financial crisis, supporting the im-

26 Furthermore, the distinction between intermediates and the capital stock can be questioned (Jones, 2013). Both types of "capital" can be viewed as produced factors of production with the same purpose: contributing productively to the finalisation of a product. The only difference is the time dimension, with the more short-lived intermediates defined as current consumption (and not as a capital investment). Corrado *et al.* (2020) argues that the distinction is particularly difficult to uphold when it comes to knowledge-based capital — a type of capital especially important for the HICs.

27 When adding lags to the capital multiplier, the elasticity of the HICs is negatively significant with lags 1-2, while the US elasticity turns weakly negative ($p<0.1$) with lags 1-3. In this sense, the difference between the HICs and the United States is reduced when dynamics, in terms of lags, are included. Moreover, the potential productivity effect of the capital import multiplier from China is not investigated further in this article, neither is the possibility that some parts of the domestic capital stock in the HICs — e.g. its ICT-related parts — have been productivity enhancing.

28 See, for example, Autor, Dorn, and Hansen (2013), Acemoglu, Akcigit, and Kerr (2015), Bloom, Draca, and Van Reenen (2016), Autor, Dorn, and Hansen (2016), Acemoglu and Azar (2020) and Autor *et al.* (2020a).

Table 4: Different Time Periods and Lag Structures for Vertical Labour Productivity

Panel A: High-income Countries

Dependent variable: vertical labour productivity	2000-2008	2009-2014	2000-2014: lag 1	2000-2014: lag 3	2000-2014: lag 4	2000-2014: lag 5
Output multiplier	-1.140***	-1.269***	-0.539**	0.181	0.184	0.388**
	(0.199)	(0.205)	(0.179)	(0.142)	(0.127)	(0.146)
Import multiplier	-0.655***	-0.798***	-0.682***	-0.498***	-0.300***	-0.151**
	(0.093)	(0.105)	(0.085)	(0.069)	(0.054)	(0.057)
Import multiplier from China	0.562***	0.381***	0.542***	0.394***	0.283***	0.213***
	(0.019)	(0.045)	(0.024)	(0.018)	(0.015)	(0.017)
R^2 - within	0.55	0.38	0.38	0.31	0.22	0.15
N	3363	2197	5090	4335	3961	3582

Panel B: United States

Dependent variable: vertical labour productivity	2000-2008	2009-2014	2000-2014: lag 1	2000-2014: lag 3	2000-2014: lag 4	2000-2014: lag 5
Output multiplier	-1.038**	-1.526	-0.447	0.640	0.407	0.617*
	(0.355)	(1.009)	(0.579)	(0.824)	(0.461)	(0.269)
Import multiplier	-0.024	-0.525	-0.584*	-0.674*	-0.461**	-0.290
	(0.136)	(0.505)	(0.251)	(0.298)	(0.165)	(0.154)
Import multiplier from China	0.283***	0.523**	0.436***	0.418***	0.344***	0.296***
	(0.046)	(0.185)	(0.072)	(0.076)	(0.042)	(0.044)
R^2 - within	0.81	0.41	0.77	0.61	0.60	0.61
N	159	107	246	211	193	175

Note: Linear fixed effect IV estimations (2SLS). Robust standard errors in parentheses, adjusted for clusters: 390 clusters for the HICs (GVCs, i.e., countries*manufacturing sub-sectors, including their domestic supply chains) and 18 clusters for the US (GVCs, i.e., manufacturing sub-sectors, including their domestic supply chains) when no lags are used. Vertical gross output is included to control for the actual level of production. The variables are expressed in constant prices with base year=2000. The instrumental variable is China's vertical labour productivity. Log values. $^{***}p < 0.001$,** $p < 0.01$,* $p < 0.05$. For 2000-2008, the F-value of the first-stage regression of the HICs (US) is 411 (258), and the elasticity of the instrumental variable is significant at $p < 0.001$. For 2009-2014, the F-value of the first-stage regression of the HICs is 258 (79), and the elasticity of the instrumental variable is significant at $p < 0.001$.

pression that the included variables and the IV strategy performs better for the period considered to be the peak years of the China shock — from China's WTO membership in 2001 until the financial crisis.

The question about the persistence of the Chinese productivity effect is addressed in the last four columns of Table 4. Three conclusions emerge. First and foremost, adding lags indicates a clear persistence: with a five years lag, the effect is still significant at $p < 0.001$ and its size is economically relevant (0.213 and 0.296). A 1 per cent increase in the use of Chinese intermediates five years ago, thus leads to a faster productivity growth with more than 0.2 per cent today.[29] Second, when adding lags, the difference in the size of the effect between the HICs and the United States is turned around, indicating that the lag structure is relatively more important in the latter. Third, when adding lags, the United States' import multiplier also turns significantly negative. This increases the similarity with the aggregate HICs, further emphasizing the role of Chinese intermedi-

29 To further investigate this longer-term effect, the fixed effect estimator is used to estimate the elasticities between two time periods, e.g. between the year 2000 and the year 2014, and between the average of the years 2000/2001 and the average of the years 2013/2014, respectively. This exercise, found in the Appendix, supports the existence of such positive longer-term productivity effects from the growing use of Chinese intermediates.

Table 5: Estimate for Separate Manufacturing Sub-sectors for Vertical Labour Productivity

High-income Countries

Dependent variable: vertical labour productivity	Import multiplier	Import multiplier from China	R^2 - within	F-value of first-stage regression	N
Food	Neg sign	0.893***	0.04	30	328
Textile and clothing	Neg sign	0.600***	0.56	74	305
Wood	Not sign	0.516***	0.57	64	279
Paper	Not sign	0.686***	0.55	58	297
Printing and recorded media	Neg sign	0.491***	0.41	45	308
Coke and refined petroleum	Neg sign	2.232*	..	14	270
Chemicals	Neg sign	0.858**	0.41	98	299
Pharmaceuticals	Neg sign	0.806*	..	82	320
Rubber and plastic	Neg sign	0.673***	0.69	60	303
Other non-metallic products	Not sign	0.518***	0.39	36	294
Basic metals	Neg sign	0.566***	0.30	15	294
Fabricated metals, except machinery and equipment	Neg sign	0.568***	0.64	51	322
Computers and electronics	Neg sign	0.339***	0.78	188	313
Electrical equipment	Neg sign	0.500***	0.78	102	327
Machinery and equipment, n.e.c.	Neg sign	0.481***	0.83	174	327
Motor vehicles	Neg sign	0.416***	0.76	159	323
Other transport equipment	Neg sign	0.422***	0.50	156	309
Furniture	Neg sign	0.645***	0.42	65	322
Repair and installation of machinery and equipment	No obs	No obs	No obs	No obs	No obs

Note: Linear fixed effect IV estimations (2SLS). Other included regressors are: output multiplier and vertical gross output. For each of the manufacturing sub-sector, the domestic supply chain is included in the variables. Robust standard errors, adjusted for 22 clusters (countries). The variables are expressed in constant prices with base year=2000. Elasticities are presented in column 2. Neg sign=negatively significant at least at p<0.05. The instrumental variable is China's vertical labour productivity. Years: 2000-2014. Log values. $^{***}p < 0.001$,** $p < 0.01$,* $p < 0.05$.

ates in the vertical specialization of the US economy.

Separate manufacturing sub-sectors

In terms of separate manufacturing sub-sectors and their production processes, how widespread is the productivity effect of the growing use of Chinese intermediates? Without enough data for the United States, this question is answered focusing on the HICs. Continuing to use equation (1) and the fixed effect estimator, Table 5 gives a clear answer to this question. But first, the first column shows that no manufacturing sub-sector, including its domestic supply chain, has a significant positive elasticity of the import multiplier, when controlling for the intermediate imports from China. On the contrary, the elasticity of the import multiplier is significantly negative in 15 out of 18 sub-sectors. Once again, this emphasizes the importance of separating out China when analyzing the productivity effects of the general increase in the use of imported intermediates within the manufacturing production processes of the HICs.

When it comes to the import multiplier from China, Column 2 shows that its elasticity is positively significant at least at $p < 0.05$ in all 18 manufacturing sub-sectors, although the results for coke and refined petroleum and pharmaceuticals, respectively, look less robust.[30] At the bottom of the table, there are five sub-sectors in which the fixed effect estimator seems to

30 When using a linear panel model with instruments and applying the fixed effect estimator, an unspecified R^2 value is, however, not necessarily a problem.

generate extra robust results: with large F-values, highly significant elasticities, and a high level of explanatory power.

Mechanisms: Three Possible Explanations

Several theoretical mechanisms can be used to explain the seemingly positive causal effect on vertical labour productivity growth in the HICs of the growing use of Chinese intermediates. Without any claim of being exhaustive, this section tries to shed some preliminary empirical light on three possible mechanisms put forward in recent China shock research.

Value added or employment?

The welfare consequences of the Chinese productivity effect depend on the channels by which the intermediates affect the productivity growth in the HICs. Therefore, and along the lines of Acemoglu, Akcigit, and Kerr (2015) and their argument for more research on the interplay between value added and employment in an IO setting: is the Chinese productivity effect explained by a positive effect on vertical value added or a negative effect on vertical employment — or both?[31] Using the same econometric approach as before, the results in Table 6 indicate that the main channel in the HICs is reduced employment: no matter the length of the lag, a growing use of Chinese intermediates seems to lead to a significant and economically relevant decrease in vertical employment. In terms of value added, there is a weak tendency of a positive, more instantaneous effect; but with longer lags, this effect seems to be reversed, indicating a double effect: reduced employment and reduced value added. For the United States, the result looks less bleak, with a positive longer-run effect on value added and no longer-run negative effect on employment. If these patterns are in accordance with reality, it would be interesting to understand what might explain the difference between the HICs and the United States.

Reduced prices

Within a neoclassical framework, prices are the main channel through which productivity effects are propagated in the production system (Acemoglu *et al.* 2021). Despite that, Jaravel and Sager (2020) argues that there are knowledge gaps about the effect of the China shock on the prices in the HICs. Their starting point is that the strong Chinese productivity growth is likely to lead to reduced Chinese prices, which in turn, through strategic price-setting, will lead to reduced producer prices (and consumer prices) in the HICs. Based on US data, they show that the growing imports from China, between 1991 and 2007, led to reduced domestic prices and therefore to large consumer surpluses.[32] In line with this, and focusing on US manufacturing price indices, Amiti *et al.* (2020) shows that China's entry to WTO in 2001 led to reduced prices; between 2000 and 2006 the

31 The same interplay has also recently been used when studying the effects on labour productivity of a growing use of robots within (US) sectors (Acemoglu and Restrepo, 2020).

32 Jaravel and Sager (2020) estimate that the consumer surplus is large enough to compensate each of the displaced US job caused by the China shock by around dollar $400000.

Table 6: The China Shock on Value Added and Employment

Panel A: High-income Countries

Dependent variable: vertical value added	No lag	Lag 1	Lag 3	Lag 5	Lag 7
Import multiplier from China	0.008	0.117**	0.062	-0.100	-0.138*
	(0.006)	(0.037)	(0.061)	(0.066)	(0.061)
R^2 – within	0.99	0.34	0.05	0.02	0.03
N	5560	5090	4335	3582	2870
Dependent variable: vertical employment					
Import multiplier from China	-0.579***	-0.425***	-0.332***	-0.313***	-0.259***
	(0.026)	(0.036)	(0.058)	(0.057)	(0.055)
R^2 – within	0.83	0.29	0.06	0.06	0.07
N	5560	5090	4335	3582	2870

Panel B: United States

Dependent variable: vertical value added	No lag	Lag 1	Lag 3	Lag 5	Lag 7
Import multiplier from China	-0.004	0.19	0.502**	0.313**	0.164*
	(0.006)	(0.121)	(0.187)	(0.097)	(0.076)
R^2 – within	0.99	0.35	..	0.04	0.09
N	266	246	211	175	140
Dependent variable: vertical employment					
Import multiplier from China	-0.380***	-0.245*	0.084	0.017	-0.002
	(0.065)	(0.111)	(0.158)	(0.083)	(0.074)
R^2 – within	0.92	0.44	0.04	0.16	0.2
N	266	246	211	175	140

Note: Linear fixed effect IV estimations (2SLS). Vertical value added is defined as the value added needed in the domestic economy in order to satisfy final demand, including all upstream/backward stages of the domestic production process. Vertical value employment is defined analogously. See Appendix for further details. Other included regressors are: output multiplier, import multiplier and vertical gross output. Elasticities and standard errors are shown in the table. Robust standard errors, adjusted for clusters: with no lag, the number of clusters is 390 (GVCs, i.e. countries*manufacturing sub-sectors, including their domestic supply chains) for the HICs and 18 (GVCs, i.e. manufacturing sub-sectors, including their domestic supply chains) for the US. The variables are expressed in constant prices with base year=2000. The instrumental variable is China's vertical labour productivity. Years: 2000-2014. Log values. $^{***}p < 0.001$,$^{**}p < 0.01$,$^{*}p < 0.05$. In the estimations with no lag, the F-value of the first-stage regression of the HICs (US) is 390 (175), and the instrumental variable is significant at $p < 0.001$.

China shock reduced manufacturing price indices by 7.6 per cent.

Along similar lines, the question addressed in this section is: does the growing use of Chinese intermediates affect the prices within the manufacturing production processes? The answer is found in Table 7. Clearly, all three deflators point in the same direction: a growing use of Chinese intermediates seems to lead to slower price increases. With the importance of including lags (Jaravel and Sager, 2020), this result seems to become more robust when such delayed effects are estimated: the size of the price effect increases with time. Although somewhat less robust, this effect seems to be larger in the United States than in the HICs. Within the setting of this article, the price effect of the China shock means that the level of real vertical value added would have been lower without the growing intermediate trade with China – and, hence, has contributed positively to the Chinese productivity effect.

Functional specialization

The growing importance of intermediates has led to new approaches to measure and understand specialization within and between countries (Pahl and Timmer, 2019). In order to trace where the value added embedded in a manufactured product is generated, one aspect of this is the movement of measurement from gross trade

Table 7: The China Shock Effect on Prices

Panel A: High-income Countries

Dependent variables: vertical price indices	No lag	Lag 1	Lag 3	Lag 5	Lag 7
Gross output price index: imp.multi from China	-0.011**	-0.022***	-0.028***	-0.033***	-0.036***
	(0.003)	(0.004)	(0.025)	(0.005)	(0.004)
Value added price index: imp.multi from China	-0.009**	-0.020***	-0.026***	-0.031***	-0.035***
	(0.003)	(0.004)	(0.004)	(0.005)	(0.005)
Intermediate price index: imp.multi from China	-0.013***	-0.024***	-0.030***	-0.034***	-0.036***
	(0.003)	(0.004)	(0.004)	(0.005)	(0.004)

Panel B: United States

Dependent variables: vertical price indices	No lag	Lag 1	Lag 3	Lag 5	Lag 7
Gross output price index: imp.multi from China	-0.053**	-0.082**	-0.073**	-0.031	-0.046*
	(0.018)	(0.025)	(0.024)	(0.025)	(0.018)
Value added price index: imp.multi from China	-0.048**	-0.075**	-0.070**	-0.029	-0.044*
	(0.016)	(0.023)	(0.024)	(0.024)	(0.018)
Intermediate price index: imp.multi from China	-0.060**	-0.090**	-0.077**	-0.034	-0.048**
	(0.021)	(0.029)	(0.026)	(0.025)	(0.018)

Note: Linear fixed effect IV estimations (2SLS). The vertical gross output price index is defined as the sectoral gross output indexes weighted by Leontief´s inverse: diagonal (go index) ∗ Leontief´s inverse. Hence, in this matrix, the column sum of manufacturing sub-sector i in country j is sector i's vertical gross output price index. The vertical value added price index and the vertical intermediate input price index are constructed analogously. Other included regressors are: output multiplier, import multiplier, and vertical gross output. The variables are expressed in constant prices with base year=2000. The table presents the elasticities and robust standard errors, adjusted for clusters: 390 (countries∗manufacturing sub-sectors, including their domestic supply chains) in the HICs and 18 in the US (manufacturing sub-sectors, including their domestic supply chains) when no lags are used. The instrumental variable is China´s vertical labour productivity. Years: 2000-2014. Log values. $^{*} = p < 0.05, ^{**} = p < 0.01, ^{***} = p < 0.001$. For the HICs (US), the F-value of the first-stage regressions is 259 (206) when no lags are used. The R^2 value ranges from 0.70 to 0.84 when no lags are used.

flows to net (value added) trade flows. Another aspect is related to the allocation of production activities between countries needed to finalize a manufactured product. With China emerging as the factory of the world, the HICs seem to have become less specialized in fabrication activities and more specialized in knowledge-intensive parts of the manufacturing production process, such as R&D, marketing, and management (Timmer *et al.* 2019).

This process of functional specialization is supported within the framework of this article. As can be seen from Table 8, a growing use of Chinese intermediates seems to have led to a growing relative use of knowledge-intensive business services (KIBS) intermediates:[33] the overall use of KIBS intermediates per unit of final demand increases when the use of Chinese intermediates increases. The size of this effect is considerably larger in the United States than in the HICs, although the level of significance is similar. The estimations on the domestic and imported use of KIBS intermediates — also presented in the table — respectively shows that this functional specialization is mainly explained by a growing use of imported of KIBS intermediates. In the HICs, the China effect on the domestic use of KIBS intermediates is negative, while it seems to be a more or less instantaneous positive effect in the United States, which disappears when longer lags are used. The overall messages from this exercise should then be that:

33 The KIBS sectors are: M69-70: legal and accounting activities, head offices; M71: architectural and engineering activities; M72: scientific research; M73: advertising and market research; M74-75: other professional, scientific, and technical activities.

Table 8: The Effect of the China Shock on Functional Specialization

Panel A: High-income Countries

Dependent variable: overall multiplier: KIBS	No lag	Lag 1	Lag 3	Lag 5
Import multiplier from China	0.219***	0.177***	0.139**	0.103*
	(0.048)	(0.047)	(0.043)	(0.049)
Dependent variable: domestic multiplier: KIBS				
Import multiplier from China	-0.035	-0.047*	-0.094***	-0.136***
	(0.021)	(0.022)	(0.022)	(0.026)
Dependent variable: import multiplier: KIBS				
Import multiplier from China	0.242***	0.224***	0.233***	0.239***
	(0.035)	(0.035)	(0.033)	(0.034)

Panel B: United States

Dependent variable: overall multiplier: KIBS	No lag	Lag 1	Lag 3	Lag 5
Import multiplier from China	1.412***	1.125***	0.900**	0.745**
	(0.158)	(0.176)	(0.265)	(0.217)
Dependent variable: domestic multiplier: KIBS				
Import multiplier from China	0.275***	0.244**	0.189	0.159
	(0.067)	(0.083)	(0.102)	(0.087)
Dependent variable: import multiplier: KIBS				
Import multiplier from China	1.052***	0.881***	0.712***	0.586***
	(0.109)	(0.113)	(0.169)	(0.139)

Note: Linear fixed effect IV estimations (2SLS). The variable overall multiplier: KIBS is defined as the total use of KIBS intermediates per unit final demand, including all upstream/backward production stages, irrespective if they are domestically or foreign sourced. The other two KIBS multiplier variables are defined analogously, but only measuring the domestic or the foreign use of KIBS intermediates per unit of final demand, respectively. Other included regressors are: output multiplier, import multiplier, and vertical gross output. The variables are expressed in constant prices with base year=2000. The table presents the elasticities and standard errors of the import multiplier from China. The instrumental variable is China´s vertical labour productivity. Robust standard errors, adjusted for clusters: 390 (countries∗manufacturing sub-sectors, including their domestic supply chains) in the HICs and 18 in the US (manufacturing sub-sectors, including their domestic supply chains) when no lags are used. Years: 2000-2014. Log values. $^{*} = p < 0.05$,$^{**} = p < 0.01$,$^{***} = p < 0.001$. In the six estimations without lags, the lowest F-value of the first-stage regression is 175.

1. the China effect on the functional specialization towards the KIBS part of the manufacturing production process seems to be more pronounced in the United States than in the HICs, and;

2. this functional specialization points in the direction of more KIBS intensive production processes, but not necessarily within the domestic production stages of the HICs (including the United States).

Has this functional specialization had any effect on the vertical labour productivity growth? Table 9 might indicate that this is the case. Both from a cross-sectional perspective and when focusing on changes over time (i.e. the fixed effect estimator), the table indicates that the overall use of KIBS intermediates — both domestically and foreign sourced — is positively correlated to vertical labour productivity. Adding lags to the fixed effect estimator,

34 When the import multiplier from China is included in these estimations, the size and significance of the elasticities presented in this table is, however, reduced. This might indicate that the productivity effect of the overall KIBS use is, at least partly, dependent on the imports of KIBS intermediates from China.

Table 9: Knowledge-intensive Business Services and Productivity and Vertical Labour Productivity

High-income Countries and United States

Dependent variable: vertical labour productivity	OLS	FE – no lag	FE – lag 1	FE – lag 3	FE – lag 5
HIC: Overall multiplier: KIBS	0.041***	0.111***	0.126***	0.159***	0.106**
	(0.006)	(0.024)	(0.027)	(0.024)	(0.034)
US: Overall multiplier: KIBS	0.145***	0.165***	0.190***	0.209***	0.171***
	(0.04)	(0.024)	(0.031)	(0.030)	(0.026)

Note: OLS and linear fixed effect (FE) estimations. Other included regressors are: output multiplier, import multiplier, and vertical gross output. The variables are expressed in constant prices with base year=2000. The table presents elasticities and robust standard errors of the variable Overall multiplier: KIBS, adjusted for clusters: 408 (countries*manufacturing sub-sectors, including their domestic supply chains) in the HICs and 18 in the US (manufacturing sub-sectors, including their domestic supply chains) when no lags are used. Years: 2000-2014. In the fixed effect estimation without lag, the R^2 value amounts to 0.33 for the HICs and to 0.82 for the US. Years: 2000-2014. Log values. $* = p < 0.05, ** = p < 0.01, *** = p < 0.001$.

this effect seems to be rather persistent and economically relevant.[34] In all five estimations, the size of the correlation is larger in the United States than in the HICs. Finally, when the import multiplier from China is included in these estimations (not shown in the table), the size and significance of the elasticities presented Table 9 is reduced. This indicates that the productivity effect of the overall KIBS use is, at least partly, caused by the imports of KIBS intermediates from China.

Is China special?: A comparison with Eastern Europe

If the results presented in this article have anything to say about the operation of real world economies, then one obvious question is: are China's intermediates a special case? Following Bloom, Draca, and Van Reenen (2016) among others, the last empirical analysis of this article therefore tries to give an answer to this question. In so doing, the causal effect on the vertical labour productivity growth of the growing use of Chinese intermediates is compared to the productivity effect of the intermediate imports from two country groups: (1) Eastern Europe and (2) the HICs themselves.[35] With this purpose, another identification strategy has to be used. The reason for this is that China's vertical labour productivity is not the most appropriate instrumental variable for the exports of intermediates from these two country groups. From the reasoning in the section on identification, and analogously following the often-used strategy in the China shock literature, the imports of Chinese intermediates among the 21 non-HIC-countries in the WIOD will be used as the instrumental variable.

Continuing the use of equation (1), Table 10 gives some conclusions. First, with high F-values, the new identification strategy generates satisfying first-stage regressions, and very much so for the effects of China's and Eastern Europe's intermediates on the HICs, respectively. When it comes to the comparison of the productivity effects in the HICs between China and Eastern Europe, the table shows that the pattern is very much the same: a significantly negative import multiplier and a positive and significant import multi-

35 For the HICs (US), the average import multiplier from Eastern Europe amounted to 0.042 (0.0006) in 2000 and to 0.049 (0.0014) in 2014. The corresponding figures for the import multiplier from the HICs are 0.216 (0.071) and 0.221 (0.073).

Table 10: China Compared with Eastern Europe

Panel A: High-income Countries

Dependent variable: vertical labour productivity	No lag	Lag 1
Import multiplier: estimation China	-0.606***	-0.561***
Import multiplier: estimation Eastern Europe	-1.053***	-1.022***
Import multiplier: estimation HIC	3.368***	3.185***
Import multiplier from China	0.500***	0.490***
Import multiplier from Eastern Europe	0.849***	0.838***
Import multiplier from HIC	-6.051***	-5.742***
R^2 – within: China	0.52	0.46
R^2 – within: Eastern Europe	0.18	0.10
R^2 – within: HIC	..	..
F-value of first-stage regression: China	709	614
F-value of first-stage regression: Eastern Europe	449	343
F-value of first-stage regression: HIC	48	51
N	5866	5377

Panel B: United States

Dependent variable: vertical labour productivity	No lag	Lag 1
Import multiplier: estimation China	0.011	-0.096
Import multiplier: estimation Eastern Europe	0.138	0.067
Import multiplier: estimation HIC	1.206***	1.089**
Import multiplier from China	0.270***	0.285***
Import multiplier from Eastern Europe	0.512***	0.527***
Import multiplier from HIC	-1.241***	-1.207***
R^2 – within: China	0.84	0.81
R^2 – within: Eastern Europe	0.72	0.67
R^2 – within: HIC	0.64	0.67
F-value of first-stage regression: China	555	506
F-value of first-stage regression: Eastern Europe	78	77
F-value of first-stage regression: HIC	37	31
N	283	262

Note: Linear fixed effect IV estimations (2SLS). Other included regressors are: output multiplier and vertical gross output. The variables are measured in constant prices with base year=2000. Robust standard errors, adjusted for 412 clusters (GVCs, i.e. countries*manufacturing sub-sectors, including their domestic supply chains) in the HIC estimations and for 19 clusters (manufacturing sub-sectors, including their domestic supply chains) in the estimations on the United States. The instrumental variable is the imports of Chinese intermediates among the 21 non-HIC-countries in the WIOD. Years: 2001-2014. Log values. $^{***}p < 0.001,^{**}p < 0.01,^{*}p < 0.05$. The import multiplier from Eastern Europe measures the use of Eastern European intermediates per unit of final demand, including all upstream stages of the domestic production process. The import multiplier from the HICs is constructed analogously.

plier from China/Eastern Europe. However, with larger elasticities for Eastern Europe's intermediates in both the HICs and the United States, the average absolute productivity effect seems to be more pronounced than the China effect. In this respect: China does not seem to be special.

On the other hand, China and Eastern Europe seem to be special in relation to the productivity effect of the use of intermediates imported from the HICs (i.e. their intra-trade of intermediates). The difference is striking. Not the least, after controlling for the import multiplier from the HICs, the import multiplier becomes positively significant and very large in absolute terms. Hence, when the import multiplier from the HICs is unchanged, a growing use of imported intermediates leads to much faster productivity growth. This gives a clear indication that the HICs' imports of intermediates from each other hold back the positive productivity effect of the growing use of imported intermediates, or the trend towards vertical specialization in the global economy. This is also shown

by the elasticity of the import multiplier from the HICs. In both the HICs and the United States, this elasticity is negatively significant and large, indicating that an increase in the use of HICs' intermediates – when the overall level of imported intermediates is unchanged – reduces the vertical labour productivity growth within the manufacturing production processes among the HICs in a substantial way.

Final Discussion

Main results

This article contributes to the literature on the China shock by investigating, for the first time, the labour productivity effect of the growing use of Chinese intermediates within almost 400 manufacturing production processes among 22 HICs. Including all stages of the production process — an approach that has lately received renewed attention in several literatures — the main results are the following.

1. Since the Millennium, the growing use of Chinese intermediates has led to a faster vertical labour productivity growth in the HICs and the United States;
2. This is the case both before and after the financial crisis;
3. The effect is identified in all — or almost all — manufacturing subsectors;
4. The effect passes several robustness tests: different definitions of the overall network of intermediate trade, inclusion of the capital stock, inclusion of lags, weighted estimations, and an alternative IV strategy;
5. China is not special: the productivity effect of the growing use of Eastern European intermediates is equally significant and larger in size;
6. A growing intra-trade of intermediates among the HICs have been detrimental to their productivity growth.

Suggested mechanisms

Among several possible mechanisms, the main reasons why a growing intermediate trade with China seems to lead to a faster productivity growth are unclear (Bloom, Draca, and Van Reenen 2016). This article has tentatively tried to shed light on three of the mechanisms discussed in the China shock literature: value added or employment, reduced producer prices, and functional specialization. The results point in the direction that reduced employment — in comparison to value added — is the most important channel behind the positive productivity effect; the growing use of Chinese intermediates reduces producer prices; and the China shock has led to a productivity enhancing functional specialization towards the use of knowledge-intensive business services intermediates. These mechanisms fit into more general arguments based on increased specialization, intensified global competition, new input combinations, and higher quality intermediates.

Future research

This article has only scratched the surface of what is possible within the chosen framework. Continuing with analyses of vertical productivity, some interesting questions are:

1. What would the productivity effect be when investigating the China effect on

all countries in the world?

2. How would the results based on a vertically integrated TFP measure compare to the results based on the vertical labour productivity measure?

3. Are there any intermediates imported from China that contribute more than others to the productivity growth in the HICs?

4. What about the productivity effect from China's exports of the capital goods included in the capital stock?

5. Is there any relation between the HICs' exports of intermediates to China and their vertical productivity growth?

6. In terms of value added, employment, and vertical productivity, does the China effect differ between different parts of the manufacturing production process in the HICs?

7. In terms of competitiveness, does a growing use of Chinese intermediates lead to improved relative productivity among the HICs?

8. In terms of the value added needed to produce the world demand for a manufactured product, does a growing use of Chinese intermediates lead to a larger share of the world market?

Final remark

The emergence of China as the factory of the world represents a rare opportunity to identify causal effects on the level of the global economy (Autor, Dorn, and Hansen, 2016). Considered as a natural experiment, the reforms in China initiated in the late 1970s have, through increased domestic productivity, led to a remarkable increase in the demand for Chinese intermediates among the HICs. This fundamental reorganization of manufacturing production seems, in turn, to have contributed to faster vertical labour productivity growth in the HICs — and, hence, to improved fundamentals for faster real wage growth. Having said that, this result by no means represents the general equilibrium effect on the labour market, but it may make one dimension of the puzzle somewhat more illuminated. And that is good enough.

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Appendix: Construction of the Main Variables

Vertical labour productivity

This variable is defined as the ratio between the (vertical) value added and (vertical) employment generated within the domestic production process in order to satisfy final demand.[36] Mathematically and using matrix notation, the vertical value added (VVA) is found by the equation:

$$VVA = VA/GO((I - A)^{-1}FD).$$

$(I - A)^{-1} = L = [l_{ijj}]$ is the Leontief inverse ($(I - A)^{-1} = I + A + A^2 + A^3 + ...$), or the total requirements matrix.[37] l_{ij} is thus a partial derivative and expresses the total effect on domestic production in sector i of a unit change in final demand in sector j ($L_{ij} = \frac{\partial x_i}{\partial f_i}$), including all subsequent rounds of indirect intermediate demand. Therefore, L describes how a change in final demand is transmitted throughout the domestic production system in wider and wider circles. VA/GO is a diagonal matrix with the ratio between domestic sectoral value added and domestic sectoral gross output on the main diagonal and zeros elsewhere. FD is a diagonal matrix with sectoral final demand on the main diagonal and zeros elsewhere. In country i, the column sum for sector j (i.e. $GVC_{i,j}$) in VVA_i is the (vertical) value added needed to satisfy sector j's final demand, including all upstream stages of its domestic production process. Vertical employment is defined in the same way, but with sectoral employment instead of sectoral value added.

Output multiplier

This variable measures the gross output needed in the domestic economy in order to produce one unit of final demand, including all subsequent rounds of indirect intermediate demand generated along the domestic supply chain (Miller and Blair, 2009). In country i, the column sum for sector j (i.e. $GVC_{i,j}$) in L_i is sector j's output multiplier. Although domestically oriented, this variable resembles to the downstream measures frequently used in the GVC literature (Antras and Chor, 2021).

Import multiplier

This variable measures the use of imported intermediates per unit of final demand, including all subsequent rounds of indirect demand for imported intermediates generated along the domestic supply chain. Mathematically, the import multiplier (IM) is found by the equation: $IM = II/GO(I-A)^{-1}$, where II/GO is a matrix with the ratios between sectoral intermediate imports and sectoral gross output. In country i, the column sum for sector j (i.e. $GVC_{i,j}$) in IM_i is sector i's import multiplier, including all subsequent rounds of indirect demand for intermediate imports generated along the domestic supply chain. Although domestically oriented, this variable resembles to the measures of foreign

36 The term "vertical" comes from the description of the column sum dimension often used in IO analysis (Miller and Blair, 2009) and from Carvalho (2014) who argues that a vertical economy is – in contrast to a horizontal economy – an economy where trade in intermediates connect sectors.

37 A is the direct requirement matrix, describing the first round effect on the intermediate demand from a unit change in final demand.

value added in exports in the GVC literature (Antras and Chor, 2021).

Import multiplier from China

This variable measures the use of Chinese intermediates per unit of final demand, including all subsequent rounds of indirect demand for Chinese intermediates generated along the domestic supply chain. Mathematically, the import multiplier from China (IMC) is found by the equation: $IMC = IIC/GO(I - A)^{-1}$, where IIC/GO is a matrix containing the ratios between sectoral intermediate imports from China and sectoral gross output. In country i, the column sum for sector j (i.e. $GVC_{i,j}$) in IMC_i is sector j's import multiplier from China, including all subsequent rounds of indirect demand for Chinese intermediates generated along the domestic supply chain.

Overall multiplier

This variable measures the gross output needed to produce one unit of final demand, irrespective of whether the intermediates are domestically or foreign sourced. It is defined as the sum of the output and import multiplier.[38]

Capital multiplier

This variable measures the use of the capital stock per unit of final demand, including all subsequent rounds of indirect demand for the capital stock generated along the domestic supply chain. Mathematically, the capital multiplier (CM) is found by the equation: $CM = CS/GO(I - A)^{-1}$. where CS/GO is a diagonal matrix containing the ratio between the sectoral capital stock and sectoral gross output on the main diagonal and zeros elsewhere. In country i, the column sum for sector j (i.e. $GVC_{i,j}$) in CM_i is sector j's capital multiplier, including all subsequent rounds of indirect demand for the capital stock along the domestic supply chain.

Vertical gross output

This variable measures the gross output needed to satisfy final demand, including all subsequent rounds of indirect demand generated along the domestic supply chain. Mathematically, vertical gross output (VGO) is found by the equation: $VGO = (I - A)^{-1}FD$, where FD is a diagonal matrix with final demand on the main diagonal and zeros elsewhere. In country i, the column sum for sector j (i.e. $GVC_{i,j}$) in VGO_i is sector j's vertical gross output, including all subsequent rounds of indirect demand along the domestic supply chain.

38 The term "overall multiplier" is my own construct.

Appendix Table A: Weighted Estimations

Panel I: High-income Countries

Dependent variable: vertical labour productivity	Weight=go	Weight=va	Weight=empl.
Import multiplier	-1.006***	-0.994***	-0.864***
	(0.154)	(0147)	(0.131)
Import multiplier from China	0.720***	0.710***	0.683***
	(0.068)	(0.065)	(0.065)

Panel II: United States

Dependent variable: vertical labour productivity	Weight=go	Weight=va	Weight=empl.
Import multiplier	-0.32	-0.367	-0.528*
	(0.255)	(0.265)	(0.237)
Import multiplier from China	0.348***	0.362***	0.401***
	(0.066)	(0.07)	(0.064)

Note: Note. Linear fixed effect IV estimations (2SLS). Other included regressors are: output multiplier and vertical gross output. *GO* weight = share of real vertical gross output, VA weight = share of real vertical value added, and empl weight = share of vertical employment. Robust standard errors in parentheses, adjusted for clusters. The instrumental variable is China's vertical labour productivity. Years: 2000-2014. Log values. $^{*} = p < 0.05,^{**} = p < 0.01,^{***} = p < 0.001$. The six estimations pass the under-identification test (Kleibergen-Papp rk LM statistic) and the weak identification test (Cragg-Donald Wald F statistic).

Appendix Table B: Another Instrumental Variable

Panel I: High-income Countries

Dependent variable: vertical labour productivity	No lag
Import multiplier	-0.606***
	(0.067)
Import multiplier from China	0.500***
	(0.016)
R^2 – within	0.52
N	5866

Panel II: United States

Dependent variable: vertical labour productivity	No lag
Import multiplier	0.011
	(0.182)
Import multiplier from China	0.270***
	(0.042)
R^2 – within	286
N	0.84

Note: Linear fixed effect IV estimations (2SLS). Other included regressors are: output multiplier and vertical gross output. Robust standard errors in parentheses, adjusted for clusters (GVCs). All variables are expressed in constant prices with base year=2000. The instrumental variable is the import of Chinese intermediates among the 21 countries in the WIOD not defined as an HIC. Years: 2000-14. Log values. $^{***}p < 0.001,^{**} p < 0.01,^{*} p < 0.05$. The F-value of the first-stage regression for the HICs (US) is 709 (555), and the instrumental variable is significant at $p < 0.001$.

Appendix Table C: Longer-term Effects of the China Shock

High-income countries

Dependent variable: vertical labour productivity	2000 vs 2014	2000-01 vs 2013-14	2000-02 vs 2012-14	2000-03 vs 2011-14	2000-04 vs 2010-14
Output multiplier	-0.467	-0.874**	-1.014**	-0.939**	-0.713*
	(0.249)	(0.299)	(0.322)	(0.332)	(0.335)
Import multiplier	-0.593***	-0.630***	-0.643***	-0.685***	-0.714***
	(0.101)	(0.107)	(0.122)	(0.132)	(0.142)
Import multiplier from China	0.467***	0.491***	0.539***	0.577***	0.593***
	(0.022)	(0.025)	(0.029)	(0.033)	(0.038)
F-value: first stage	490	418	387	339	298
R^2 - within	0.77	0.71	0.69	0.65	0.58
N	750	753	754	754	756

Note: Linear fixed effect IV estimations (2SLS). Robust standard errors in parentheses, adjusted for 386 clusters (countries*manufacturing sub-sectors, including their domestic supply chains). The instrumental variable is China's vertical labour productivity. Vertical gross output is included to control for the actual level of demand. Years: 2000-2014. Log values. $^{***} = p < 0.001$,$^{**} = p < 0.01$,$^{*} = p < 0.05$. With two time periods, the fixed effect estimator generates the same result as the first-difference estimator.