Productivity Growth in Construction Value Chains

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Abstract

The construction industry has suffered from low productivity growth in recent decades. Motivated by the economic importance of the industry, we revisit the construction productivity puzzle by analyzing the construction value chains of 12 European countries using data from the World Input–Output, the EU KLEMS databases and complementary datasets. We decompose construction-related value added and productivity contributions to both the construction industry and the rest of the value chain and show that the traditional focus on the construction industry is adversely restrictive for understanding productivity growth in construction activities. There is a substantial contribution of construction-related value added generated in other industries, and the productivity growth in the value chains has, for the most part, been seen outside the construction industry. Furthermore, we show that there is a strong, long-term relationship between construction-related patents and the improvement of total factor productivity in the value chains, but the chains typically do suffer from low efficiency in the use of information technology.

Construction industry is a significant contributor to economic activity in most countries. On average, it accounts for approximately 6 to 9 per cent of economies' gross domestic product (Arditi and Mochtar, 2000). However, productivity growth in the construction industry is commonly and persistently low compared to many manufacturing and service industries (Bankvall *et al.*, 2010; Tran and Tookey, 2011). It is more a rule than an exception that there has been no productivity growth or even a declining productivity in the European construction industries over a period of several decades.

According to O'Mahony and van Ark

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(2003), annual labour productivity growth in the construction industry was approximately 1 percentage point lower than in the total economy from 1979 to 2001. According to more recent EU KLEMS data[2], the industry has on average shown only negligible labour productivity growth between 2001 and 2015. Such a controversial finding raises questions not only about the origins of the poor performance, but also about the quality of the underlying productivity statistics. This article addresses a key challenge of the latter: the fragmentation of the construction value chains.[3] Before analyzing the fragmentation, we, however, need to share some insights on the complexity of the construction value chains and the operational environment.

Construction is on-site work, while industrialization of construction, with focus on prefabrication, can be seen as a structural action to diminish on-site activities. For example, pre-cast concrete is a manufactured product, while installing pre-cast is construction work. In either case — prefabrication focused or on-site built — flawless communication, precise timing and efficient logistics pose an arduous and critical triad to any construction project. Much of the technological progress in constructed products consists of increasing the amount of work that is done in a plant setting as opposed to on-site, and transporting those components to a construction site for more straightforward installation or erection.

Declining or stagnant labour productivity in the construction industry could be associated with overall gains in the efficiency with which constructed products are installed, but those gains could show up as improvements in productivity in the manufacturing sector instead of the construction industry itself. Plant production enables transparent control of production processes, incurs potential cost savings through coordinated purchases and standardized repetitive work phases, offers natural opportunities for process and material development including easier monitoring thereof, as well as other gains associated typically with economies of scale. An additional benefit particularly valuable in construction is the total control of climate that plant production offers: no rain, no frost, no gusts.

Thus, only a part of the construction value creation is generated by the construction industry on-site, and hence a focus on on-site productivity only hides substantial networks of technologically progressive manufacturing and business services. A comprehensive value chain perspective is important in providing further understanding about the construction industry's or-

2 The EU KLEMS data used in the analysis are discussed in the second section.

3 In what follows, we refer to all construction-related economic activity, including and beyond the construction industry as the construction value chain. The construction industry is narrowly defined according to the ISIC Rev. 4 industry classification (F) and by its productivity growth we refer to the value-added based measurements in the industry. Instead, the construction value chain involves all production activities contributing to the production of the built environment. The value chain constitutes the value added of the construction industry and the value of the intermediate goods and services, both domestic and foreign, used by the industry to produce its gross output. To the extent that other industries provide value added to the construction value chain, they are considered as construction-related activities and according to our methodology, hence a part of the construction value chain. While construction sector has been used both as a synonym to construction industry and as a more general term, we use it only when citing corresponding literature.

ganization and performance, as the value chain approach makes more visible both the substantial role of upstream industries to which construction industry has backward linkages as well as technology and knowledge investments as a source of productivity growth in the entire value chain.

Our work builds on a novel decomposition of the value-added contents of the outputs and contributions of the construction industry and of the other sectors in the upstream value chain. We combine the World Input–Output Database (WIOD) and a method suggested by Los, Timmer, and de Vries, (2016) to measure the value-added content of different economic activities based on the data. Accordingly, we extracted construction activities from the WIOD for 12 European countries.[4] Furthermore, we studied the productivity growth contributions of the industries that participate in the value chains. In particular, we used data on the generated value-add in the value chains to weight the corresponding industry-level productivity growth measurements in the EU KLEMS database and complementary datasets, to thereby account for their contribution of the value-added factor in growth (Wolff, 1994; Timmer, 2017).

While more typical value chain analysis tracks the value creation paths of individual projects and even single products (see Ali-Yrkkö, Seppälä, and Mattila, 2016 and references therein), the approach is not feasible for an entire, highly diversified sector ranging from family house building and land reclamation to oil rig construction. Not only is the construction industry heterogeneous, but also the importance of intermediate goods varies widely — the value of gross output in residential constructions is much greater than in road construction, and installation of underwater pipelines requires huge state-of-the-art machinery. A reciprocal approach using WIOD and KLEMS type data responds to the analysis challenge posed by extensive and complex sectors such as construction.

Our analysis shows that the focus on the construction industry is restrictive from the perspective of understanding productivity growth in construction activities: there is a substantial amount of construction-related value added generated in other industries. We find that roughly half of the total value added in the construction value chains is generated within the construction industry — a proportion common for most observed value chains. The other half of the value added is generated by other industries, involving both manufacturing and business services. Our findings suggest that the role of the business service sector, in particular, is important and has increased in the years from 2001 to 2014. Moreover, the productivity growth in the construction value chains has, for the most part, occurred in the upstream part of the value chain, while the role of the on-site construction industry is weak or even negative. This finding suggests that a focus on the on-site construction industry leads to a suppressing bias in the productivity of construction activities. We also identify a strong long-term relationship between construction-related

4 AUT, BEL, CZE, DEU, DNK, ESP, FIN, FRA, GBR, ITA, NLD, and SWE.

patents and the improvement of total factor productivity (TFP). To this end, we used a panel vector error correction model. Finally, we present how the value chains typically suffer from low efficiency in the use of information technology and due to high administrative costs.

In what follows, we first review the literature. We then introduce our value chain productivity measurement methodology and apply it to study the composition of the construction value chain and the productivity growth in the value chain. We also analyze statistically the effects of patents and information technology in the value chain. Finally, we conclude with a discussion.

Literature Review

This article contributes to several strands of literature. First, it introduces a novel way to analyze the role of different industries by extracting the construction value chains in the global input–output data, more commonly used in an international trade context (Los, Timmer, and de Vries, 2016; Ali-Yrkkö and Kuusi, 2017, 2019). It is one of the few attempts to capture the full economic scope of the construction value chain, beyond the contribution of the construction industry as more narrowly defined in International Standard Classification of All Economic Activities ISIC (ISIC, 2008) and its regional derivatives such as the European Nomenclature of Economic Activities NACE (REGULATION (EC) No 1893/2006).

Previously, Squicciarini and Asikainen (2011) used a discretionary classification of the construction sector to core and supporting (non-core) industries. They extended beyond the core construction sector by adding activities from other sectors that fully or principally depend upon or are functional to core construction activities. Their findings suggest that the indicators for composition, structure, value added, skills, and R&D input and output of the construction sector change substantially when a broader definition of the sector is applied.

Another strand of literature discusses how different features of the construction value chains affect their ability to increase productivity. Construction companies face difficulties in implementing innovation to enhance productivity due to the fragmented characteristic of construction and the high degrees of specialization in its processes, together with production activities carried out within single projects (Winch, 1998; Gann, 2000; Davis *et al.*, 2016). The construction industry also suffers from fragmentation owing to the temporary nature of project execution and the specialism incorporated into a project (Sullivan and Harris, 1986).

The fragmentation brings about well-known problems that may contribute to low productivity growth: capital-heavy approaches to construction bring high fixed costs that are difficult to cut in downturns, and profit margins are slim in the fragmented construction industry. These factors tend to keep investments at low levels (Economist, 2017a). Moreover, due to the complex nature, construction projects are exposed to high risk that is coupled with the problems of imperfect information (Lau and Rowlinson, 2011). The customized nature of most projects, often arising from complex legislation, further limits the usual advantages of size, preventing the generation of bigger, more productive companies. Construction projects are typically tendered out into a cascade of subcontractors, each operating at their industry's low profit margins. The subcontractors have evident incentives to maximize their profit or at least minimize losses — not that uncommon in single subprojects — rather than collaborate to contain overall costs of the entire project.

All in all, the fragmentation often results in numerous structural problems. Projects often lack repeatability and efficiency in performing recurring activities, the resource profiles of value chain members are not strongly shaped by the relationship, and operational decisions about one sub-entity are typically made independently of decisions about other sub-entities (Ketokivi *et al.*, 2017).

Naoum's (2016) study revealed that the rate of labour productivity on-site can be greatly affected by the fragmentation, for example, through ineffective project planning, delays caused by design error and variations, problems in the communications systems, design and buildability related issues such as specifications, and the procurement method. Zhai *et al.* (2009) showed that construction labour productivity is positively related to the use of automation and integration of projects. Ruddock and Ruddock (2011) identified information and communications technology (ICT) capital as the fastest growing input in construction, while it has only a modest share in overall input costs. Productivity growth might be explained by the level of investment in ICT (ICT capital growth); however, problems arise due to the time lag for a new technology to reach its full potential.

These findings correspond with the literature regarding productivity in general. Quite a few studies have shown that the impact of ICT at the industry level plays only a limited role as a source of productivity growth. This finding is reported by, among others, Stiroh (2002a), Draca, Sadun, and Van Reenan (2006), and Inklaar *et al.*, (2008). Complementary innovations in organizations are often needed to foster successful adaptation of ICT (Bresnahan, Brynjolfsson, and Hitt, 2002). Consistently, O'Mahony and Vecchi (2005), Oulton and Srinivasan (2005), and Venturini (2009) report a larger long-term effect. Following a growing body of literature that connects TFP and patents (Romer, 1990; Grossman and Helpman, 1994; Madsen, 2008; Coe, Helpman, and Hoffmaister, 2009), we include into our approach a module on how patents have improved productivity.

The challenges of innovation and ICT investment may become particularly large when their productivity contributions are considered jointly for the whole value chain. A strong interaction emerges in the value chain when the new technology generates positive productivity externalities or there are unmeasured complementary innovations that are made during the adaptation of the technology (Stiroh, 2002b; Basu and Fernald, 2007). The particular importance of a functional value chain strikes us as an intuitive one, as the positive role of technology is likely to accumulate and result in stronger ecosystems (Ketokivi *et al.*, 2017) that foster more efficient formalization of interactions, specialization of firms, and joint real-time decision-making in the value chain. On the other hand, fragmentation of the value chain may make the productivity impact of ICT weaker.

Finally, the literature discusses the measurement techniques of construction industry productivity. The introduction of the EU KLEMS database has made it easier to perform comparative analyses at the industry level. Some papers have analyzed productivity dynamics in construction (Crawford and Vogl, 2006; Abdel-Wahab and Vogl, 2011; Ruddock and Ruddock, 2011), but the measurement is not without problems. Sveikauskas *et al.* (2016) argued using detailed US data that productivity growth in the construction industry may be somewhat greater than previous results suggest. Notably, there have been attempts to include details of project-level dynamics to better understand the increase in the quality of construction outputs (Sezer and Bröchner, 2014). One conclusion is that it should be possible to use the increasing volume of available performance indicator data collected for construction projects, and to thereby improve the quality of the productivity statistics. However, this approach has so far been infeasible due to the limited resources of measurement activities.

Statistical problems and the heterogeneity of data collection practices call for caution in making comparisons of productivity levels across countries (Vogl and Abdel-Wahab, 2015). Acknowledging the difficulties, our approach is to use productivity growth statistics to analyze changes in value chains over time. Moreover, due to the short-term impacts of business cycles (Abbott and Carson, 2012), we focus on the average behavior of the sector over the different phases of the most recent business cycle (2001–2014).

Methodology for measuring productivity in the value chains

In essence, we combined industry-level productivity contributions of different inputs in the EU KLEMS data with the WIOD data to compute the productivity contributions of different industries in the value chain.

Data

In our analyses, we used the 2016 release of the WIOD database.[5] It builds on a set of consistent time series of national supply and use tables that are constructed by harmonizing the corresponding national tables and benchmarking them against the national accounts. The national tables are then used to derive international tables. They build on the disaggregation of imports by country of origin and use category by using bilateral trade data. Finally, the national tables are combined to yield corresponding world tables, which are then transformed into a world input–output table (WIOT) (Dietzenbacher *et al.*, 2013; Timmer *et al.*, 2015, 2016).

The data comprise sector-level World Input–Output Tables (WIOTs) with underlying data for 44 countries and 56 sectors, which serve as a model for the rest of the

5 Timmer *et al.* (2015); http://www.wiod.org/home

world for the period 2000–2014.[6] Together, the countries cover more than 85 per cent of the world GDP (at current exchange rates). WIOTs are built based on National Accounts data, which are extended by means of disaggregating imports by country of origin and using categories to generate international supply and use tables (Timmer *et al.*, 2016).

Our approach combines the WIOD database and the EU KLEMS database (Jäger, 2017, www.euklems.net), the World KLEMS, the WIOD Socio Economic Accounts (SEA) data (available at the WIOD 2016 database), and the Penn World Table (version 10.0, https://www.rug.nl/ggdc/productivity/pwt/). The combination of several datasets is necessary to meet with our method's high requirement of factor input data. The WIOD data show value added contributed by all countries and industries across the world. The contributions can come from any industry and any country within the WIOD database, directly or indirectly needed to produce the final product, in the construction industry, in a given country. However, a further step is necessary to translate the values from each country industry into the implied factor usage.

The EU KLEMS data provides the main factor data for our analysis. EU KLEMS is constructed to provide internationally comparable and consistent time series on outputs, inputs, and productivity by industry (Jäger, 2017). The database includes EU-25 and several other industrialized countries. In general, data for 1970–2005 are available for the old EU-15 nations as well as for the United States, Australia, and Japan. Series from 1995 onward are available for the new EU member states that joined the EU on May 1, 2004. The coverage of the data differs across countries, industries, and variables. In practice, we found that the 12 construction value chains used in our analyses have the best scope of productivity data both within-country and internationally. For the rest of the world economy that is not covered by the EU KLEMS database, we collected complementary data from the world KLEMS, WIOD SEAs and the Penn World Table.

Measurement of the value-added contribution in the value chain

We applied a measurement framework for the decomposition of value added in the construction value chain grounded on hypothetical extraction, a parsimonious mathematical technique based on an input–output representation of the global economy (Los, Timmer, and de Vries, 2016). This approach has clear economic intuition and can easily be applied to the data. It compares the actual, global value-added distribution with a hypothetical distribution in cases where there are no production activities related to construction.

6 The countries have been chosen by considering both the data availability of sufficient quality and the desire to cover a major part of the world economy. They include 27 EU countries and 15 other major countries. Data for the 56 sectors are classified according to the International Standard Industrial Classification Revision 4 (ISIC Rev. 4). The tables adhere to the 2008 version of the System of National Accounts (SNA). The dataset provides World Input–Output Tables (WIOTs) in current prices, denoted in millions of dollars (Timmer *et al.*, 2016). It is notable that we control the monetary inflation component by using VA shares that divide industry VA by the overall value chain VA.

The difference is defined as the value added of construction activities. In the hypothetical world, the construction industry in each observed country seizes the opportunity to generate final goods, as well as intermediate products, to other industry–country pairs.

In our analysis, we first constructed a value-added matrix VA that allocated the total value added into the contributions of different intermediate good producer industries globally across time, countries, and industries. By extracting applicable elements from the input-output tables, we then constructed the counterfactual scenario ($VA*$) and calculated their element-wise difference to provide us with the corresponding value-added contributions $\Delta VA = VA - VA^{*}$. We describe the methodology rather extensively in the Appendix.

Factor-based productivity contributions to construction output

We next discuss our approach to measuring the productivity contributions of different sectors. The classical KLEMS productivity approach is commonly used to analyze productivity of the construction industry. In an approach that builds on Jorgenson, Gollop, and Fraumeni (1987), gross output production function includes two types of factor inputs, capital (K) and labour (L), and three types of intermediate inputs, energy (E), materials (M), and services (S). This approach offers useful insights into the changes in efficiency with which the inputs are being used in the production process of the industry (or firm), as measured by productivity growth.

Recently, modelling and measuring patterns of substitution and productivity growth at the industry (or firm) level has become both more difficult and less meaningful (Timmer, 2017). With increased outsourcing and offshoring, the share of industry value added in gross output is declining. Consequently, analyses based on industry value added have to rely on strong assumptions of separability. However, as conditions that are jointly necessary and sufficient for the existence of sectoral value-added functions are typically rejected in the data, intermediate inputs should be treated in the same way as factor inputs in the productivity analysis. Thus, the robustness of the KLEMS approach becomes increasingly dependent on proper price measurement of intermediate inputs.[7] These are increasingly hard to measure due to the practice of transfer pricing in multinational enterprises, the difficulty in pricing the flow of intangibles, and an inadequate statistical system to track prices of intermediates when quality is improving (Houseman and Mandel, 2015; Timmer, 2017).

We propose a production function (F) where final output is based on factor inputs only, including both domestic and foreign factors, similar to Wolff (1994) and Timmer (2017). Using the information from

7 Arising methodological complexities concerning the measurement of a value chain function are discussed by OECD (2001). Fundamentally, the deflation of gross output is conceptually straightforward, whereas the volume change for value added combines the volume change for gross output and intermediate inputs, and thereby constitutes a general-form double deflation.

the hypothetical extraction method, discussed above, the flow of intermediate inputs will be netted out so that the production function of a final good can be expressed in terms of factor inputs only. They are located both in the industry where the last stage of production takes place and in other industries (domestic and foreign) contributing to earlier stages of production. The actual contributions are measured individually for each country's construction value chain by using the hypothetical extraction method.

Formally, let F be a translog production function for the construction aggregate product: $f = F(\Lambda, K, T)$, where Λ is the column vector of labour requirements for production, K is similarly a column vector of capital requirements, and T denotes technology. The factor requirements are measured using industry-specific input-to-value-added ratios.

Under the standard assumptions of constant returns to scale and perfect input markets, the productivity decomposition into components of the different industries and the TFP can be derived (see Appendix for further details). The decomposition of the real gross output growth in the construction industry (Y_{t,F^s}) into the contributions of factors and the TFP (π) as residual is:

$$\begin{aligned}\Delta \log(Y_{t,F^s}) = {} & \overline{\alpha^L}(F^s)\Delta \log(\Lambda_t) \\ & + \overline{\alpha^K}(F^s)\Delta \log(K_t) \\ & + \Delta\pi(F^s)\end{aligned} \tag{1}$$

where the resource-use vectors of all industries (in discrete time) are $\Delta \log(\Lambda_t)$ and $\Delta \log(K_t)$. L_t, K_t, and Y_t are the labour and capital inputs, and the industry's gross outputs, respectively, while $\alpha^L(F^s)$ and $\alpha^K(F^s)$ are constructed Törnqvist shares of the resource costs. They combine the value-added contribution of each industry–country observation to the construction value chain (obtained with hypothetical extraction), and the corresponding measures of the labour and capital cost shares from the productivity data (KLEMS, SEA, Penn).

To add further detail to the analysis, we decomposed labour growth contribution into the components arising from the change in the number of hours and change in the composition of the labour force. Labour is cross-classified in EU KLEMS according to educational attainment, gender, and age, with the aim to proxy for differences in work experience, providing 18 labour categories (3 × 2 × 3 types). It is assumed that service flows are proportional to the hours worked, and wages reflect the relative marginal productivity of labour (Jäger, 2017). This allowed us to decompose the labour input growth into contributions of labour composition LC and number of hours H. However, this approach can be criticized, especially due to the division of labour into gender groups in which wages may not, in fact, reflect productivity differences. Therefore, we reconstructed labour composition indices that only distinguish between educational attainment. In the 2017 EU KLEMS data, we were able to recalculate the composition from 2008 onwards, while we use the original composition for the previous years and in the EU KLEMS-based productivity measurements that are made for comparisons.[8]

Furthermore, we distinguished between ICT capital and non-ICT capital. In the EU KLEMS data, distinctions are made between three ICT assets (office and computing equipment, communication equipment, and software) and four non-ICT assets (transport equipment, other machinery and equipment, residential buildings, and nonresidential structures). ICT assets are deflated using a quality-adjusted investment deflator based on the methodology described in Timmer *et al.* (2007). Capital service flows are derived by weighting the growth of stocks by the share of each asset's compensation in total capital compensation using the Törnqvist index. In this way, the aggregation takes into account the widely different marginal products from the heterogeneous stock of assets by using weights related to the user cost of each asset. The user cost approach is crucial for the analysis of the contribution of capital. This approach is based on the assumption that marginal costs reflect the relative marginal productivity in the corresponding capital type.

A practical caveat of the empirical analysis based on the EU KLEMS data, is that we cannot account for all the involved productivity growth of industries in the value chain. While the share of included value added is large (on average 86 per cent of all value added in the considered construction value chains), it can be argued that merely focusing on the EU KLEMS data might bias our results. To overcome this problem, we thus use alternative datasets to approximate the missing factors.

First, we employed the World KLEMS dataset that includes KLEMS data for Japan, Korea and Russia. This data typically spans from the mid-2000s to the early 2010s. Where data was still missing, we used a combination of WIOD SEA data and the Penn World Table data. The SEAs provide labour input in hours at the industry level for the WIOD countries. To complement this data, we used the Penn World Table data to measure the country-level average labour quality index. We adjust the SEA labour inputs to provide an approximate, yearly labour services index for each industry in each country. For capital services, we use the PENN world table country-level averages for countries where other data are unavailable.

Different datasets are combined by measuring the factor growth components from each dataset, and then replacing observations accordingly, when data are found to be missing. Finally, the WIOD database includes a rest-of-the-world category that aggregates data from small emerging and developing countries. While its contribution to the value chains is negligible, we still provide an approximation of its factor use for the sake of completeness. To this end, we assume that the factor intensities correspond to the Chinese factor intensity at the same time period.

By this, we have completed the description of our methodology. We provide the results in three sections below, each titled with what we regarded as a key finding.

8 We find that the differences are in practice small, and do not affect our main results.

Table 1: Value-add Shares of Different Sectors in Construction Value Chains

	Share of the value chain value VA in 2014 (%)				Change of the share between 2000 and 2014 (percentage points)			
	Primary	Manufacturing	Construction	Services	Primary	Manufacturing	Construction	Services
AUT	3	16	53	28	1.1	0	-6.1	4.9
BEL	4	16	43	37	0.7	-1	-2.3	2.7
CZE	3	14	44	38	-0.7	-5.9	1.1	5.6
DEU	2	15	49	33	0.7	-3.2	1	1.5
DNK	4	16	41	38	0.6	-4.2	-1.7	5.3
ESP	3	11	53	33	0.6	-5.7	-4.4	9.6
FIN	6	19	45	30	1	-4.9	2.2	1.7
FRA	3	15	49	34	0.5	-3.6	3.4	-0.3
GBR	3	12	56	29	0.7	-1.1	-1.1	1.5
ITA	3	13	48	36	-0.1	-5.8	6.6	-0.6
NLD	3	19	44	33	1.8	1.9	-2	-1.7
SWE	4	12	50	34	0.5	-4.1	0.4	3.2
Average	**3**	**15**	**48**	**34**	**0.6**	**-3.1**	**-0.3**	**2.8**

Note: Primary production = industries A and B, manufacturing = industries 10-33, construction = industry F, and Services = all other industries in the international standard industrial classification (ISIC).

Source: WIOD database and authors' calculations

The Role of Services has Increased in Construction Value Chains

We first analyzed the industry composition of value added in our value chains. We decomposed the value added in the chain to components from four sectors: primary, manufacturing, construction, and services. The results are reported in Table 1. As this analysis did not involve productivity measurements, we can analyze the full decomposition of the value added based on the WIOD database.

Our results show that, on average, the construction industry only accounted for roughly 48 per cent of the value-add generated in the value chain in 2014. The second largest contributing sector was services, which generated 34 per cent of the value-add, while manufacturing and primary production generated 15 per cent and 3 per cent, respectively. The results also suggest that there are similarities in the organization of construction activities across countries. For example, in 2014, the share of the construction industry varied within 41 per cent and 56 per cent of total value added. The largest shares of the construction industry were found in the UK (56 per cent), Spain (53 per cent), and Austria (53 per cent), while the smallest shares were measured in Denmark (41 per cent), Belgium (43 per cent), and the Czech Republic (44 per cent).[9]

Over time, there have been some changes in the shares. From 2000 to 2014, the average share of the service sector increased 2.8 percentage points, while the share of the manufacturing sector decreased by roughly the same amount. A closer look at the data showed that this development seems to be associated with a reallocation of tasks in

9 Sector-wise, the largest average value-added shares of non-construction industries in the considered GVCs are for professional, scientific, technical, administrative and support service activities (10 per cent); wholesale trade, except of motor vehicles and motorcycles (5 per cent); rubber and plastics products, and other non-metallic mineral products (4 per cent); basic metals and fabricated metal products, except machinery and equipment (4 per cent); transport and storage (3 per cent); real estate activities (3 per cent); financial and insurance activities (3 per cent); mining and quarrying (3 per cent); retail trade, except of motor vehicles and motorcycles (2 per cent); electrical and optical equipment (2 per cent).

Table 2: **Growth and its Components: Comparison of the Construction Value Chain and the Construction Industry**

Panel A: Real gross output growth and its components in the construction value chain								
	Capital share (%) (a)	Growth components excluding hours: (b) = c+d+g	TFP growth contribution (c)	Capital growth contribution (d)	ICT growth contribution (e)	NIT growth contribution (f)	Labour composition contribution (g)	Hours contribution (h)
AUT	38	0.6	0.2	0.5	0.2	0.2	-0.1	0.2
BEL	41	1.7	-0.4	1.3	0.3	0.8	0.8	0.4
CZE	40	2.1	0.9	1.1	0	1.2	0.1	-0.7
DEU	25	1	-0.3	0.1	0	0.1	1.2	-1.6
DNK	27	0.3	0	0.3	0	0.2	-0.1	-0.5
ESP	39	2.1	2.3	0.6	0	0.7	-0.8	-2.1
FIN	26	0.5	0.5	0.2	0.1	0.2	-0.3	-0.1
FRA	27	0.3	-0.1	0.5	0.1	0.3	-0.1	0.3
GBR	20	0	-0.8	0.4	0.1	0.2	0.4	0
ITA	34	-1	-0.6	-0.1	-0.1	0.1	-0.3	-1
NLD	20	0.9	0.3	0	0	0.1	0.5	-1.6
SWE	38	0.9	-0.3	1.5	0.2	1.2	-0.3	0.8
Average	**31**	**0.8**	**0.2**	**0.5**	**0.1**	**0.4**	**0.1**	**-0.3**

Panel B: Real value-added growth and its components in the construction industry								
	Capital share (%) (a)	Growth components excluding hours: (b) = c+d+g	TFP growth contribution (c)	Capital growth contribution (d)	ICT growth contribution (e)	NIT growth contribution (f)	Labour composition contribution (g)	Hours contribution (h)
AUT	36	-1	-1	0.2	0.1	0.1	-0.1	0
BEL	39	2	0.2	1.6	0.2	1.4	0.2	0.3
CZE	30	1.3	-0.4	1.2	0.1	1.1	0.5	-0.4
DEU	5	0	-0.3	0.1	0	0.1	0.2	-1.3
DNK	15	1.1	-0.1	0.2	0.1	0.1	1.1	-0.4
ESP	38	-0.2	-1.8	1.1	0	1.1	0.5	-2.8
FIN	9	-0.2	-0.6	0.4	0	0.4	-0.1	0.5
FRA	18	-1.5	-1.9	0.3	0.1	0.2	0.2	1.1
GBR	10	0.3	-0.1	0.2	0	0.1	0.3	0.6
ITA	27	-1.1	-1.5	0.3	0	0.3	0.1	-0.3
NLD	1	0.2	-0.4	-0.1	-0.1	0	0.7	-1.2
SWE	33	-0.7	-1.8	1.6	0	1.5	-0.4	1.2
Average	**22**	**0**	**-0.8**	**0.6**	**0**	**0.5**	**0.3**	**-0.2**

Note: All columns express annual, average (real, simple mean) percentage point growth contributions 2000-2014. TFP is the total-factor productivity, ICT is information and communications technology capital stock, and NIT is the traditional capital stock. Construction output's growth accounting in the value chain was conducted by using the methodology outlined in Section 3, while the construction industry value-added growth decomposition uses the methodology and data of the real value-added based growth accounting measurement of industry F in the EU KLEMS database.

Source: EU KLEMS, World KLEMS, WIOD SEA, Penn World Table and authors' calculations.

construction activities from the construction industry to various business services. There are three main contributing industries to the increase of the services sector: (1) professional, scientific, technical, administrative, and support service activities (+ 1.6 percentage points); (2) financial and insurance activities (+ 0.5 points); and (3) wholesale trade, except of motor vehicles and motorcycles (+0.4 points).

Productivity Growth in the Construction Value Chain is Higher than in the Construction Industry

We analyze the origins of productivity growth in the value chains using the methodology on factor-based accounting of the industry growth contributions as presented in Section 3.

Our baseline findings show that the construction value chain is rather different from the construction industry in terms of capital intensity and its sources of growth (see Table 2).[10] The average capital intensity (the share of capital income in value added) in the value chain is 9 percentage points greater than that of the construction industry (31 vs. 22 per cent) for the measured part of the value chain. This suggests that the return of production capital per unit of nominal output is higher in construction value chains, indicating that either there is more capital or the production is more profitable.

For a deeper understanding, we analyzed the average real gross output growth rate of the value chain, while excluding the role of merely changing working hours. The average growth rate in the construction value chain has been 0.8 per cent per year, while in the construction industry, the growth (based on the EU KLEMS productivity data on the industry corresponding to ISIC Code F) has been negligible. The rates include the contributions of capital and labour quality deepening and TFP. The difference is explained by many factors: better performance of TFP, capital deepening, and increases in the quality of labour, with the productivity (TFP) growth being the single greatest contributing factor. The finding suggests that the benefits of the organization of construction activities in global value chains may be underestimated when traditional productivity statistics are used.

A few methodological comments should be made. First, it is notable that our choice of correcting the labour composition component by focusing on differences in education has a non-trivial effect on the structure of growth in the value chain. When the EU KLEMS original composition is used, the labour composition effect is estimated to be on average 0.3 percentage points larger, while correspondingly the TFP growth is 0.3 percentage points weaker. While these differences do not affect the overall growth excluding the contribution of working hours, we report an alternative calculation in the Appendix. Furthermore, as we combine data from different sources, not all data includes decomposition of the capital growth into ICT and non-ICT component. When such distinction is not possible, the contribution is merely reported as a part of the overall capital component, while the sub-components are 0 in Table 2. Thus, generally $d \neq e + f$.

Our findings, of course, mask a considerable amount of heterogeneity in country-level construction activities. Particularly interesting is the Belgian construction industry with its marine construction activities — oil platforms, dredging, undersea building, quay construction, etc. — residing at the high end of the productivity distribution. Excluding the contribution of hours, the rate of productivity growth in this industry has been 1.7 pps per year.

10 The first part of the table decomposes real output growth of the entire construction value chain. It constitutes all the construction value chain that includes the value added of the construction industry and the value of the intermediate goods and services, both domestic and foreign, used by the construction industry to produce its gross output. In the latter part, the construction industry is narrowly defined according to the ISIC Rev. 4 industry classification (F) and by its growth decomposition we refer to the value-added based KLEMS measurements for the industry.

Table 3: Growth and its Components: Comparison of the Construction Value Chain and the Construction Industry

Panel A: Contribution of the upstream part of the construction value chain

	VA share (%) (a)	Capital share (%) (b)	Growth components excluding hours: (c) = d+e+h	TFP growth contribution (d)	Capital growth contribution (e)	ICT growth contribution (f)	NIT growth contribution (g)	Labour composition contribution (h)	Hours contribution (i)
AUT	45	41	0.5	0.1	0.4	0.2	0.2	0	0.2
BEL	54	42	0.9	0.1	0.5	0.2	0.1	0.2	0.4
CZE	56	47	0.6	0	0.6	-0.1	0.7	0.1	-0.3
DEU	52	44	0.2	0.1	0	0	0.1	0.1	-0.5
DNK	59	36	0.2	0	0.3	0	0.2	-0.1	-0.2
ESP	46	39	-0.4	0	0	0	0.1	-0.3	-0.6
FIN	56	39	0.4	0.3	0	0.1	0	0.1	-0.4
FRA	51	36	0.5	0	0.3	0.1	0.2	0.1	0
GBR	42	34	0.7	0.2	0.3	0.1	0.1	0.1	0.1
ITA	53	41	-0.5	-0.1	-0.2	-0.1	0	-0.1	-0.6
NLD	51	39	0.2	0.1	0	0	0	0.1	-0.5
SWE	49	43	0.7	0	0.7	0.2	0.4	0	0.3
Average	**51**	**41**	**0.3**	**0.1**	**0.2**	**0.1**	**0.2**	**0**	**-0.2**

Panel B: Contribution of the construction industry part of the value chain

	VA share (%) (a)	Capital share (%) (b)	Growth components excluding hours: (c) = d+e+h	TFP growth contribution (d)	Capital growth contribution (e)	ICT growth contribution (f)	NIT growth contribution (g)	Labour composition contribution (h)	Hours contribution (i)
AUT	55	38	-0.5	-0.6	0.1	0	0.1	-0.1	0
BEL	46	35	1.5	0.1	0.7	0.1	0.7	0.6	0
CZE	44	36	0.4	-0.2	0.5	0.1	0.5	0.1	-0.4
DEU	48	13	1.1	-0.1	0.1	0	0	1.2	-1.1
DNK	41	17	-0.2	-0.3	0.1	0	0	0	-0.3
ESP	54	38	-0.9	-1	0.6	0	0.6	-0.5	-1.5
FIN	44	23	-0.4	-0.3	0.2	0	0.2	-0.3	0.4
FRA	49	26	-1	-1	0.1	0	0.1	-0.2	0.3
GBR	58	17	0.3	-0.1	0.1	0	0.1	0.3	-0.1
ITA	47	31	-0.7	-0.7	0.1	0	0.1	-0.1	-0.5
NLD	49	16	0.2	-0.2	0	-0.1	0	0.4	-1.1
SWE	51	34	-0.4	-0.9	0.8	0	0.8	-0.3	0.5
Average	**49**	**27**	**-0.1**	**-0.4**	**0.3**	**0**	**0.3**	**0.1**	**-0.3**

Note: All columns express annual, average (real, simple mean) percentage point growth contributions 2000-2014. TFP is the total-factor productivity, ICT is information and communications technology capital stock, and NIT is the traditional capital stock. GVC productivity contributions of the different parts' inputs were measured by using the methodology outlined in Section 3, while TFP estimates build on the value-added based measurements of TFP in the EU KLEMS database, as weighted by the Törnqvist shares of individual industries in the GVC value added.

Source: EU KLEMS, World KLEMS, WIOD SEA, Penn World Table and authors' calculations.

Growth has followed consolidation and investments, driven by knowledgeable customers who have demanded extreme precision despite very difficult building environments. These are understandable requirements, since the difference between smooth flow and utter catastrophe lies in the quality of the seam in underwater oil pipes. Increased size and complexity of projects has spurred the development further by forcing companies to use machines instead of labour (Economist, 2017b).

The improvements in growth performance, clearly seen in our data, can be traced to mechanical improvements of tools, increased measurement and use of ICT, and introduction of modular building. However, the cases of Spain and the Czech Republic seem quite different. In those countries, the growth improvements (in both cases 2.1 pps annually when the contribution of hours is excluded) are associated with large reductions of the labour force, which suggests that the initial level of productivity may have been rather low, but more recently, the country has caught up in productivity with respect to other countries.

At the low end, the construction industries in Italy and France show poor growth performance. What is interesting, however, is that in the case of France, our accounting of the value chain TFP growth at least partly offset the poor developments of the industry. This suggests that productivity growth within the construction value chain has shifted more towards upstream industries and away from the construction industry itself: a phenomenon which has not been visible in traditional statistics.

We further decomposed the real gross output growth of the value chain into contributions of the domestic construction industry and those from upstream (all other industries) in the value chain (Table 3). This approach focuses on the different components of the construction value chain measurement in Table 2, but distinguishes between growth components originating in the different parts of the value chain. In the case of the growth contribution to the inputs, it is straightforward.[11]

However, TFP contribution of the total value chain cannot be allocated directly to either part of the value chain. To overcome this shortcoming, we collected value-added growth-based TFP growth estimates from the EU KLEMS dataset, and following Timmer (2017), used them to separate TFP growth contributions of domestic construction industry from the rest of the upstream value chain. Effectively, the GVC-based TFP can be viewed as a weighted average of TFP of the production's last stage and upstream, with the value-added shares of the industries in the value chain as weights. While this approach is not without caveats and can be done only for industries that have KLEMS-based TFP calculations, it may still help to source the GVC-based TFP back to the different parts of the chain.

11 In practice, we allocate real output growth of the entire construction value chain (Panel A of Table 2) to the industry and the rest of the value chain components by first dividing construction value chain's value added to the industry part (ISIC Rev. 4 classification F) and the rest of the value chain part. We then measure the corresponding factor use separately for the different parts.

Table 4: Decomposition of the Real Construction Gross Output Growth to the Foreign Components

	Foreign part of the value chain								
	VA share (%) (a)	Capital share (%) (b)	Growth components excluding hours: b = c+d+g	TFP growth contribution (d)	Capital growth contribution (e)	ICT growth contribution (f)	NIT growth contribution (g)	Labour composition contribution (h)	Hours contribution (i)
AUT	20	41	0.3	0.1	0.2	0.1	0	0	0.1
BEL	29	43	0.6	0	0.4	0.2	0.1	0.1	0.3
CZE	23	43	0.2	0.1	0.1	0	0.1	0	0
DEU	15	45	0.1	0	0.1	0.2	-0.1	0	-0.1
DNK	27	42	0.3	0.1	0.2	0	0.1	0	0
ESP	12	42	-0.1	0	-0.1	0	0	0	-0.2
FIN	21	44	0.2	0.1	0.1	0	0.1	0.1	-0.1
FRA	16	42	0.2	0.1	0.2	0.1	0.1	0	0.1
GBR	12	44	0.2	0	0.2	0	0.1	0	0.1
ITA	12	43	0	0	-0.1	0	0	0	-0.2
NLD	25	42	0.3	0.1	0.1	0	0	0.1	-0.1
SWE	20	42	0.2	0	0.2	0.1	0.1	0	0
Average	**19**	**43**	**0.2**	**0**	**0.1**	**0.1**	**0**	**0**	**0**

Note: All columns express annual, average (real, simple mean) percentage point growth contributions 2000-2014. TFP is the total-factor productivity, ICT is information and communications technology capital stock, and NIT is the traditional capital stock. GVC productivity contributions of the foreign inputs were measured by using the methodology outlined in Section 3, while TFP estimates build on the value-added based measurements of TFP in the EU KLEMS database, as weighted by the Törnqvist shares of individual industries in the GVC value added.

Source: EU KLEMS, World KLEMS, WIOD SEA, Penn World Table and authors' calculations.

When we measure the contribution of the upstream TFP growth in this manner, shown in Table 3, the results suggest that upstream contributed substantially more to the overall productivity growth of the construction value chain. The TFP growth contribution of upstream was roughly 0.1 percentage points per year, while the construction industry's contribution was −0.4 percentage points. However, a significant part of the overall TFP growth in the value chain remains in our analysis unexplained. This is in particular due to the low TFP growth contribution that arises from the EU KLEMS-based measures of the construction industry. As a result, a large portion of the overall GVC-based TFP growth remains unallocated to either parts of the chain.

What might explain these dynamics? One natural explanation for low productivity growth in the construction industry is that there is a shift of the more productive tasks from construction to the upstream part of the value chain. As more productive tasks are shifted to the upstream part of the value chain, the remaining industry tasks are less productive. However, the productivity of the total value chain has nevertheless increased through reallocation of the tasks. This may not appear in the traditional TFP measurements. In particular, if production moves to industries with higher TFP levels in the upstream, it is likely to show up as an increase in the overall productivity through value chain TFP residual beyond the TFP growth measured from the industry-level.

The results may partly reflect measurement problems too. It could be that the growth of the output volume index may be underestimated, as was suggested by previous papers in the literature (Harrison, 2007). Moreover, the validity of the analysis of TFP into the industry location of productivity growth in the GVC depends heavily on the quality of the intermediate input deflator (Timmer, 2017).

We also studied the role of the value chain in output growth by the origin of the supplier (Table 4).[12] In particular, we divided the chain into components that reflect growth components in the domestic and foreign parts of the value chain, and again collected information on the TFP growth from the EU KLEMS measurements.

It turned out that the role of the foreign part was not dominant in productivity dynamics. In terms of the capital deepening and improvements of the labour composition, the foreign part of the chain contributed only roughly 0.2 percentage points per year to the overall productivity growth, whereas the rest can be assigned to the domestic part of the value chain or the overall efficiency gains in it. Note that in Table 4, we only report the growth components in the foreign part, while the domestic part is the residual between it and the overall growth in the chain (Table 2).

Innovations Support Long-term TFP, while Administrative Costs and the Efficiency of ICT Adoption Pose Challenges

TFP of the entire construction value chain reflects the total productivity of all industries that interact within the field of construction. By looking at the complete value chain, we can assess the role of factors that may influence productivity growth. This may help to better understand the determinants of productivity growth of construction activities as well as further validate our approach. As each factor requires separate datasets, our first task was to identify potential factors and justify their relevance. We ended up assessing three factors: innovativeness, administrative costs, and ICT investments. Our reasoning and data collection went as follows.

First, we expected that the degree of construction-related innovativeness is positively related to TFP. While there is no unique way to measure innovativeness, we resorted to one standard measure: the number of construction technology related patents granted in the corresponding country. To this end, we identified all International Patent Classification (IPC) patent classes that we assessed to have a potential link to the construction industry. This yielded a list of 49 patent classes for further analysis.

As the definition of construction is broad, it is most probable that some patent classes are missing, and some might be superfluous. However, we deem the approach to be transparent, straightforward and sufficiently consistent. The list covers a wide variety of different patent classes, including innovations in materials, construction technology, lighting, electricity, and air-conditioning systems (see Appendix 2 for patent classifications). Importantly, these innovations are made not only by the

12 In practice, we allocate real output growth of the entire construction value chain (first part of Table 2) to domestic (omitted in the Table) and foreign (reported in the Table) components based on the nationality of the construction industry. The procedure is similar to the one that we use to construct Table 3.

construction industry but also possibly by other industries in the construction value chain. The inclusion-exclusion boundary was set at patent classes that would most likely be exploited mainly in sectors outside the construction value chain.[13]

Second, we expected administrative costs to lower the efficiency of the value chains, as administrative costs are widely perceived as non-productive additional costs, and then turn into obstacles for optimal allocation of resources. We studied this potential effect using internationally comparable data provided by the World Bank Group's *Doing Business* project from year 2006 to 2014. With a warehouse as the representative example, the project recorded all official costs associated with completing the procedures to legally build a warehouse.[14] The administrative costs are presented as a percentage of the warehouse value.

Third, ICT projects have a virtually universal tendency to exceed original resource allocations, be it in terms of time or costs. The challenges, but also prospects of ICT investments may become particularly large when considered jointly for the entire value chain. Strong positive interactions may emerge in the value chain when new ICT technology generates positive productivity externalities or when there are unmeasured complementary innovations that are made during the adaptation of the technology (Stiroh, 2002b; Basu and Fernald, 2007). Due to these factors, the neoclassical growth assumptions may not apply, and the elasticity of ICT in the production function may not match the measured input share of ICT. As a result, a direct relationship between ICT capital and measured TFP growth may arise. We applied our previously collected growth accounting data to study this question.

For estimating the roles of each factor, we resorted to panel data estimations using yearly data and the value chains of different countries as panel units. We estimated a panel error correction model to analyze the long-term relationship between TFP and the different factors. First we studied the time series properties of our variables of interest. We found that the index of TFP, the cumulative capital and labour contributions — constructed by summing the yearly log-point contribution terms — and the level of patent intensity are trend stationary and cointegrated of order 1.[15]

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13 Because TFP growth measures the growth of productivity and is not, per se, related to the size of the sector, we studied the intensity of patent activities by dividing the total number of patents by the number of employees in the construction industry. We total the number of construction-related patent applications to the EPO by applicant country of residence and application year.

14 See, World Bank, *Doing Business* reports 2006-2014. https://elibrary.worldbank.org/. The data include the costs associated with obtaining land use approvals and preconstruction design clearances; receiving inspections before, during and after construction; obtaining utility connections; and registering the warehouse at the property registry. It is calculated as a percentage of the warehouse value. Nonrecurring taxes required for the completion of the warehouse project are also recorded. Sales taxes (such as value added tax) or capital gains taxes are not recorded. Nor are deposits that must be paid up front and are later refunded.

15 By using Im–Pesaran–Shin and Fisher-type tests in Stata (xtunitroot package), we find that the zero hypotheses of all panels having unit roots cannot generally be rejected. However, in the case of patent intensity, it is possible that the variable was (weakly) stationary after controlling for a linear time trend. We also test the cointegration of the variables by using the xtcointtest package in Stata and found that the cointegration relationship cannot generally be rejected, based on Kao, Pedroni, and Westerlund types of cointegration tests.

Cointegration, indeed, indicates that there may be a common growth element showing as a linear relationship between the variables, in the form of a stationary linear combination. Failure to account for it may result in spurious correlations between the variables. Accordingly, we studied separately the short-term dynamics and long-term equilibrium relationships between the different factors and TFP (O'Mahony and Vecchi, 2005).

To establish a long-run relationship between TFP and the different input growth contributions, we first need to make a few, additional methodological remarks concerning the applied statistical model.

We used the so-called mean group estimator developed by Pesaran, Shin, and Smith (1999). Our application, to estimate a common long-term relationship for each construction value chain, was as follows:

Let us denote TFP as π_{it} and the contributions of the different factors as c^{factor} (patents, administrative costs, or ICT) respectively. Then, the relationship for the value chain $i = 1,2,\ldots,12$ and time period $t = 2001,2002,\ldots,2014$ is:

$$\pi_{it} = \theta_{ifactor} c_{it}^{factor} + \mu_i + \epsilon_{it}. \quad (2)$$

With our variables being I(1)[16] and cointegrated, the error term is I(0) for all i. The corresponding auto-regressive, distributed-lag specification of the relationship between TFP and the contributing variables can be expressed in the error correction form:

$$\begin{aligned} \Delta\pi_t = {} & \phi_i(\pi_{it-1} - \theta_{i0} - \theta_{ifactor} c_{it}^{factor}) \\ & + \delta_{ifactor} \Delta c_{it}^{factor} + \delta_{it} t \\ & + \delta_{it}^{SQ} t^2 + \epsilon_{it}, \end{aligned} \quad (3)$$

where the first term is the long run cointegration relationship between TFP and input contributions. The θs denote the long-term elasticity of different factor contributions with TFP, the δs are the short-term elasticities, and ϕ_i is the error correction speed of the adjustment parameter. The key parameters of interest are long-term elasticity of patent intensity $\theta_{ifactor}$ and the error correction speed of adjustment.

Table 5 concludes the results of the error correction analysis. We considered three specifications (a-c), separately for the entire construction value chain (GVC TFP), and for the corresponding EU KLEMS-based core construction industry (value-added based TFP). Specification (a) includes patent intensity as the explanatory factor variable. Specification (b) considers administrative costs as the explanatory factor variable. Specification (c) analyzes the relationship between ICT capital growth

16 where I() denotes the order of integration.

17 While in the neoclassical growth model, TFP estimates should be "free" from such factor contributions, the correlation may arise from spillovers, omitted variables, embodied technological progress, measurement errors, or reverse causality (Stiroh, 2002a). In particular, the correlation may turn negative if there are adaptation frictions (Basu and Fernald, 2007). As ICT growth, we used the ICT capital growth component of our previous analysis in case of the whole GVC. For the industry, we used the EU KLEMS ICT capital growth component.

18 We also considered higher order trends, but they do not significantly affect our results. On the other hand, we found that using only a linear trend would be too restrictive an assumption.

component and TFP.[17] All three models include quadratic year trends.[18] Table 5 shows estimates from the different pooled mean group specifications, which allows for heterogeneous short-run dynamics and common long-run relationships. The reported short-term dynamic parameters are the averages of the corresponding value chains.

Our results show that more intensive long-term engagement in patenting activities is systematically linked with value chains that have higher TFP growth. The point estimates of the long-term relationship in Table 5 (row "Patent intensity θ_{PAT}") was 1.028. The coefficient implies the effect of one patent or more per 1,000 employees to the growth rate of TFP. For the whole value chain, the rate by which the current state is corrected towards the long-term relationship is 33.5 per cent per year, as indicated by the speed of the adjustment parameter. In the case of the construction industry only, we found a similar relationship, but this relationship was weaker than in the case of the full value chain (0.726), while the long-term relationship is captured faster.

In the value chain, the analysis suggests that one standard deviation increase in patenting is associated with a long-term increase in productivity through higher TFP by roughly 25 per cent, while the positive effect is one quarter weaker for the industry-only-based TFP.

We then considered the role of administrative costs. Administrative costs show a negative and statistically significant long-term relationship to the GVC-based TFP (−0.019). In this case, however, there was no inertia in reaching the long-term relationship, as indicated by the speed of adjustment close to 100 per cent. This might partially reflect the short dataset that we had for the administrative cost parameter. In case of the industry-based TFP, we found that the long-run relationship is positive. This finding strikes us initially as counter-intuitive. However, it might in fact reflect industry productivity remaining higher where the productive parts of the chain remain in the industry due to administrative costs slowing down development of the larger value chain.

The analysis suggests that one standard deviation increase in administrative costs (1.5 per cent increase in the administrative costs as relative to the building costs) is associated with a long-term decrease in productivity of the value chain by roughly 2.8 per cent through lowered TFP.

Finally, we analyzed the association between an ICT capital growth component and TFP growth. Our results suggest that there are major adjustment frictions in the value chains. The neoclassical ICT capital contributions may have overestimated the effect on productivity, leading to negative correlation with TFP, even in the long run. It may be that productivity growth could indeed be explained by the level of investment in ICT, but problems arise due to the time lag for a new technology to reach its full potential, and such lags may simply extend beyond the length of our data set. The pace of adjustment towards the long-term effect is relatively fast, which may indicate that the data is not sufficient to observe very low-frequency connections.

In the case of the industry-only-based TFP, the low productivity impacts of ICT are pronounced. This might indicate that

Table 5: Results of the Error Correction Model Analysis of the Link Between Underlying Factors and Total Factor Productivity (TFP)

Dependent variable TFP	Construction value chain			Construction industry		
	(a) Patent intensity	(b) Administrative cost	(c) ICT contribution	(a) Patent intensity	(b) Administrative cost	(c) ICT contribution
Pooled mean group normalized cointegrating vector						
Patent intensity	1.028***			0.726***		
(standard error)	(0.253)			(0.166)		
Administrative costs		-0.019***			0.008***	
(standard error)		(0.004)			(0.002)	
ICT comp. contribution			-2.023***			-9.041***
(standard error)			(0.609)			(2.449)
The average short-run dynamic coefficients						
Δ Patent intensity	0.016			0.047		
Δ Administrative cost		0.008			-0.056	
Δ ICT comp. contribution			1.608			-11.166
Linear time-trend comp.	5.445*	0.87	6.841***	-1.511	-9.568	-0.509
Quadratic time-trend comp.	-0.001*	0	-0.002***	0	0.002	0
Constant	-5.5e+03*	-861.192	-6.9e+03***	1529.35	9635.556	516.65
Speed of adjustment	-0.335**	-1.022***	-0.608***	-0.488***	-0.881***	-0.570***
Number of observations	143	88	156	143	88	156
Number of value chains	11	11	11	11	11	11

Note: The confidence levels are *p < .05; **p < .01; ***p < .001

Source: EU KLEMS, World KLEMS, WIOD SEA, Penn World Table and authors' calculations

the benefits, although weak, are better captured by the GVC-based TFP estimates. In the value chain, the analysis suggests that one standard deviation increase in ICT capital growth contribution (1.2 percentage points) is in association with a roughly 2.5 per cent long-term decrease in (TFP) productivity.

To study the robustness of these findings, we considered models where we jointly studied the role of different factors. While this was not possible for administrative costs due to the limited amount of data, a model that included both patents and ICT showed that similar relationships hold true also in a joint model. Moreover, we also tested alternative estimators, namely the Dynamic Common Correlated Effects Estimator. For patents and administrative costs our results were similar, while the ICT effects suggest that the results may not be robust to potential statistical caveats in

19 We used the statistical package xtdcce2 by Ditzen (2018). The package aims at correcting a few potential caveats in the basic model. First, if a lag of the dependent variable is added, endogeneity occurs and adding solely contemporaneous cross-sectional averages is not sufficient any longer to achieve consistent estimates. We also tested for weak cross-sectional dependence in our panel data. Cross-sectional dependence in the error term occurs if dependence between cross-sectional units in a regression is not accounted for. The results are available from the authors upon request.

the setup.[19] Consequently, we acknowledge that the limited size of our dataset allows only to make tentative conclusions from the analysis.

All in all, our analysis suggests that the GVC-based TFP measurements provide intuitive relationships between key underlying factors, and they seem to be stronger than with traditional, industry-only-based TFP estimates. Results suggest that productivity growth in the construction value chains is fostered by innovativeness, while administrative costs and the low efficiency in the use of ICT may hold back their productivity potential. Our analysis also seems to suggest that the investment frictions in ICT are felt more strongly in the industry (larger negative coefficient) and the effects of patents are stronger in the overall value chain. This is indicative for the differentiated effects of the underlying factors in different parts of the value chains.

Conclusions

In this article, we presented our study of the construction value chains and their productivity. We decomposed the value-added contents of the construction outputs of 12 European countries to the contributions of the entire construction value-chain: construction industry and other construction-related sectors in the upstream value chain. We combined the WIOD data and several international productivity datasets. Using the method suggested by Los, Timmer, and de Vries (2016), we measured the value-added content of the value chain through the exclusion of construction activities from the WIOD.

We found that roughly half of the total value added in the construction value chains was generated in the upstream industries of the value chains; a finding that is common in all observed value chains. The rest of the value added was generated by other industries involving both manufacturing and business services. In particular, we found that the role of the business services sector is important and has increased further over the years 2001 to 2014.

We also used information concerning the value chains to measure their overall productivity growth by accounting for the value-added factor contributions of different parts of the value chain (Wolff, 1994; Timmer, 2017). We showed that there has been more productivity growth in construction activities when the productivity improvements in the upstream part of the production chain are considered. There has been a transformation of production toward a larger role for the upstream value chain that had not so far been documented, while the role of the construction industry in total productivity growth was weak. This reallocation of productivity provides at least a partial explanation for the low productivity growth statistics of the construction industry.

We also showed that there is a strong long-term relationship between construction-related patents and the improvement of TFP in the value chain. This strong effect likely reflects positive productivity effects from increased knowledge. On the other hand, our results also suggested that there are major adjustment frictions due to administrative costs and adoption of ICT in the value chains.

All in all, our results show that the focus on the construction industry is a restrictive one when production value chains are more and more fragmented between the construction industry, manufacturing, and business services. A value chain perspective is pivotal in providing further understanding about the organization and performance of construction. A wider perspective makes more visible also the struggles in the adoption of technology striving to make the value chains more efficient. Together, our results suggest that future tools to improve the productivity in construction are likely to be found from more efficient and flexible formalization of interactions in the value chain that are fostered by innovation, more efficient use of ICT, and lowered administrative costs.

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Appendix

Measurement of the value-added contributions in the construction value chains

We will next formally represent how we used the exclusion method. First, we partitioned the global input–output table such that we had the construction industry in country s, F^s, and the rest of the world economy r containing all other industries in country s and all industries in other countries c in the world. We can construct Matrix A as follows:

$$A = \begin{bmatrix} A_{F^sF^s} & A_{F^sr} \\ A_{rF^s} & A_{rr} \end{bmatrix}$$

A, that contains the input coefficients a_{ij}, which give the global value units of intermediate goods from industry i that are required to produce one value unit of gross output in industry j. In A, the numbers of the rows and columns are the same and equal the numbers of total national industries (the number of countries, C, times the number of industries, I). For the final demand block, we similarly define a matrix of final demand flows Y, the row elements being different final demand classes (in total: 5 different classes) and columns indicating flows from i to j, with the length $C * I$.

With our decomposition, $A_{F^sF^s}$ represents the purchase requirements of the construction industry from itself in country s, while A_{rF^s} gives the requirements by all other industries for construction products bought from the construction industry of country s. For the final demand block, we can similarly write:

$$Y = \begin{bmatrix} y_{F^sF^s} & y_{F^sr} \\ y_{rF^s} & y_{rr} \end{bmatrix},$$

in which the vectors $y_{F^sF^s}$ and y_{F^sr} represent the values of flows from the construction industry in country s to all final users of its products and to final users in other industries.

We then construct the value chain matrix, VA, that contains industry- and country-specific value-added contributions. The ratios of value added to gross output in industries in countries are contained in a row vector v. The length of this vector equals the numbers of industries, with VA ratios for industries as first elements ($\tilde{v}$) and zeroes elsewhere: $\tilde{v} = [\tilde{v}\ 0]$. Then, we follow Los *et al.* (2018) and collect the actual VA distribution in the global value-chain matrix (VA), that is:

$$VA = v(I - A)^{-1}Y * i$$

in which i is a column vector where all elements are unity, implying that it sums the elements in each of the rows of the matrix Y. The VA matrix has the same dimensions as A, including the contributions of each industry to the overall VA of other industries. The element $(I - A)^{-1}$ is the well-known Leontief inverse, in which I is the identity matrix of appropriate dimensions. When multiplied with final demand, the Leontief inverse calculates the gross output in the industries producing the final products and also the output in industries producing the intermediate inputs required for this (Los, Timmer, and de Vries, 2016). In particular, VA can be interpreted as the limiting value of the infinitely long sum of VA contributions, with the number of stages varying from 1 to ∞.

What amount of value added in industry–country pair j should be attributed to the construction value chain? To measure this, we created a hypothetical world in which the construction industry in country s seizes the opportunity to generate final goods, as well as intermediate products, to other industry–country pairs. Formally, by using our decomposition, we set the intermediate flows $A_{F^sr} = 0$, yielding:

$$A^*(F^s) = \begin{bmatrix} A_{F^sF^s} & 0 \\ A_{rF^s} & A_{rr} \end{bmatrix},$$

and similarly, all the final goods $y_{F^sF^s} = 0$ and $y_{F^sr} = 0$:

$$Y = \begin{bmatrix} 0 & 0 \\ y_{rF^s} & y_{rr} \end{bmatrix}.$$

The hypothetical value added in industry j can be obtained by post-multiplying the hypothetical Leontief inverse with the hypothetical final demand as:

$$VA_j^*(F^s) = v_j(I - A^*(F^s))^{-1}Y^*(F^s) * i.$$

Following the logic of hypothetical extraction, the value added in construction activities for industry–country j can be derived as the difference in VA in the actual and hypothetical situations:

$$\Delta VA_j(F^s) = VA_j - VA_j^*(F^s),$$

and $\Delta VA_j(F^s)$ correctly measures the indirect and direct effects on the value chains that follow from the exclusion of the construction industry in s, F^s.

Importantly, we can study the value-added contribution from any individual sector in the construction value chain by changing vector v_j. In particular, we can focus on the construction industry's contribution to the value chain by instead setting $v_{F_s} = \bar{v}_{F_s}$, while other elements are set to 0. On the other hand, by setting $v = \bar{v}$ for industries other than construction while setting the construction industry elements to 0, we can focus on the rest of the value chain.

Details of the productivity decomposition

Under our assumptions, we can define productivity growth (total factor productivity growth in the production of construction output) in the global value chains of construction by the weighted rate of decline of its total labour and capital requirements:

$$\frac{\delta\pi}{\delta t}(F^s) = -\overline{\alpha^L}(F^s)\frac{\delta\Lambda}{\delta t} - \overline{\alpha^K}(F^s)\frac{\delta K}{\delta t},$$

where $\frac{\delta\Lambda}{\delta t}$ and $\frac{\delta K}{\delta t}$ are vectors of the changes in the labour and capital requirements, respectively, and α^L and α^K are the weights given by a (row) vector of value shares with elements reflecting the costs of labour and capital from all country sectors used in the production of one unit of construction product, respectively. In discrete time, the resource use vectors are $\frac{\delta\Lambda}{\delta t} = \Delta\log(\Lambda_t)$ and $\frac{\delta K}{\delta t} = \Delta\log(K_t)$, where L_t,K_t are the labour and capital inputs.

To measure the value share vectors, we note first that for a single element of the factor share vectors, it holds

$$\alpha_j^L(F^s) = \Delta VA_j(F^s) * \alpha_j^{VA,L}$$
$$\alpha_j^K(F^s) = \Delta VA_j(F^s) * \alpha_j^{VA,K},$$

where $\Delta VA_j(F^s)$ is the value-added contribution of industry–country j to construction value chain s that is obtained after setting $v_j = \bar{v}_j$ and zero otherwise, while the counterfactual without the construction sector is defined by setting $A = A^*(F^s)$ and $Y = Y^*(F^s)$, as defined in the previous subsection. $\alpha_j^{VA,L}$ and $\alpha_j^{VA,K}$ are the KLEMS-based or other productivity data-based measures of the labour and capital shares in industry–country j, respectively. As time is discrete, the value-added content is estimated by using the standard Törnqvist shares of the corresponding yearly factor shares $\overline{\alpha^L} = (\alpha_{-1}^L + \alpha^L)/2$ and $\overline{\alpha^K} = (\alpha_{-1}^K + \alpha^K)/2$. Here, we refer to the year t (α) and year $t-1$ shares (α_{-1}).

Appendix 1: Growth Decomposition of the Value Chain with the EU KLEMS Original Labour Composition

Real construction gross output growth and its components in the value chain								
	Capital share (%) (a)	Growth components excluding hours: b = c+d+g	TFP growth contribution (c)	Capital growth contribution (d)	ICT growth contribution (e)	NIT growth contribution (f)	Labour composition contribution (g)	Hours contribution (h)
AUT	38	0.6	0.1	0.5	0.2	0.2	0	0.2
BEL	41	1.8	0.1	1.3	0.3	0.8	0.4	0.4
CZE	40	2.1	0.5	1.1	0	1.2	0.5	-0.7
DEU	25	1	0.3	0.1	0	0.1	0.6	-1.6
DNK	27	0.3	-0.4	0.3	0	0.2	0.3	-0.5
ESP	39	2.1	1.3	0.6	0	0.7	0.2	-2.1
FIN	26	0.5	0.3	0.2	0.1	0.2	-0.1	-0.1
FRA	27	0.3	-0.7	0.5	0.1	0.3	0.5	0.3
GBR	20	0	-1.2	0.4	0.1	0.2	0.8	0
ITA	34	-1	-1.1	-0.1	-0.1	0.1	0.2	-1
NLD	20	0.9	-0.1	0	0	0.1	1	-1.6
SWE	38	0.9	-0.7	1.5	0.2	1.2	0.1	0.8
Average	**31**	**0.8**	**-0.1**	**0.5**	**0.1**	**0.4**	**0.4**	**-0.5**

Appendix 2: Patent Classifications

B28B	Shaping clay or other ceramic compositions; shaping slag; shaping mixtures containing cementitious material, e.g. Plaster (foundry moulding b22c;working stone or stone-like material b28d;shaping of substances in a plastic state, in general b29c;making layered products not composed wholly of these substances b32b;shaping in situ, see the relevant classes of section e)
B28C	Preparing clay; producing mixtures containing clay or cementitious material, e.g. Plaster (preparing material for foundry moulds b22c0005000000)
B28D	Working stone or stone-like materials (machinery for, or methods of, mining or quarrying e21c)
B66B	Elevators; escalators or moving walkways (life-saving devices used as an alternative to normal egress means, e.g. Stairs, during rescue to lower persons in cages, bags, or similar supports from buildings or other structuresâ a62b0001020000;â equipment for handling freight or for facilitating passenger embarkation or the like to aircraft b64d0009000000;braking or detent devices characterised by their application to lifting or hoisting gear b66d0005000000)
C04B	Lime; magnesia; slag; cements; compositions thereof, e.g. Mortars, concrete or like building materials; artificial stone; ceramics (devitrified glass-ceramics c03c0010000000); refractories (alloys based on refractory metals c22c); treatment of natural stone
E01B	Permanent way; permanent-way tools; machines for making railways of all kinds (derailing or rerailing blocks on track, track brakes or retarders b61k;removal of foreign matter from the permanent way, vegetation control, applying liquids e01h)
E01C	Construction of, or surfaces for, roads, sports grounds, or the like; machines or auxiliary tools for construction or repair (forming road or like surfaces by compacting or grading snow or ice e01h)
E01D	Bridges (bridges extending between terminal buildings and aircraft for embarking or disembarking passengers b64f0001305000)
E01F	Additional work, such as equipping roads or the construction of platforms, helicopter landing stages, signs, snow fences, or the like
E01H	Street cleaning; cleaning of permanent ways; cleaning beaches; cleaning land; dispersing fog in general (mowers convertible to apparatus for sweeping or cleaning lawns or other surfaces, e.g. To remove snow, or capable of sweeping or cleaning lawns or other surfaces a01d0042060000;cleaning in general b08b)
E02B	Hydraulic engineering (ship-lifting e02c;dredging e02f)
E02C	Ship-lifting devices or mechanisms
E02D	Foundations; excavations; embankments (specially adapted for hydraulic engineering e02b); underground or underwater structures
E02F	Dredging; soil-shifting (winning peat e21c0049000000)
E03B	Installations or methods for obtaining, collecting, or distributing water (drilling wells, obtaining fluids in general from wells e21b;pipe-line systems in general f17d)
E03C	Domestic plumbing installations for fresh water or waste water (not connected to either water-supply main or to waste pipe a47k;devices of the kind used in the ground e03b, e03f); sinks
E03D	Water-closets or urinals with flushing devices; flushing valves therefor
E03F	Sewers; cesspools
E04B	General building constructions; walls, e.g. Partitions; roofs; floors; ceilings; insulation or other protection of buildings (border constructions of openings in walls, floors, or ceilings e06b0001000000)
E04C	Structural elements; building materials (for bridges e01d;specially designed for insulation or other protection e04b;elements used as building aids e04g;for mining e21;for tunnels e21d;structural elements with broader range of application than for building engineering f16, particularly f16s)
E04D	Roof coverings; sky-lights; gutters; roof-working tools (coverings of outer walls by plaster or other porous material e04f0013000000)
E04F	Finishing work on buildings, e.g. Stairs, floors (windows, doors e06b)
E04G	Scaffolding; forms; shuttering; building implements or aids, or their use; handling building materials on the site; repairing, breaking-up or other work on existing buildings
E04H	Buildings or like structures for particular purposes; swimming or splash baths or pools; masts; fencing; tents or canopies, in general (foundations e02d)
E05B	Locks; accessories therefor; handcuffs
E05C	Bolts or fastening devices for wings, specially for doors or windows (latching means for sideboard or tailgate structures for vehicles b62d0033037000;fastening devices for constructional or engineering elements e04, f16b;locks, fastening devices structurally or operatively combined or having significant cooperation with locks e05b;means for operating or controlling wing fasteners in conjunction with mechanisms for moving the wing e05f)
E05D	Hinges or suspension devices for doors, windows or wings (pivotal connections in general f16c0011000000)
E05F	Devices for moving wings into open or closed position; checks for wings; wing fittings not otherwise provided for, concerned with the functioning of the wing
E05G	Safes or strong-rooms for valuables; bank protection devices; safety transaction partitions (alarm arrangements per seg08b)
E06B	Fixed or movable closures for openings in buildings, vehicles, fences, or like enclosures, in general, e.g. Doors, windows, blinds, gates (shades or blinds for greenhouses a01g0009220000;curtains a47h;lids for car boots or bonnets b62d0025100000;sky-lights e04b0007180000;sunshades, awnings e04f0010000000)
E06C	Ladders (e04f0011000000 takes precedence;step-stools a47c0012000000;adaptation of ladders to use on ships b63b, to use on aircraft b64;scaffolding e04g)
E99Z	Subject matter not otherwise provided for in this section
F21H	Incandescent mantles; other incandescent bodies heated by combustion
F21K	Non-electric light sources using luminescence; light sources using electrochemiluminescence; light sources using charges of combustible material; light sources using semiconductor devices as light-generating elements; light sources not otherwise provided for
F21L	Lighting devices or systems thereof, being portable or specially adapted for transportation

Appendix 2: Patent Classifications (cont'd)

F21S	Non-portable lighting devices; systems thereof; vehicle lighting devices specially adapted for vehicle exteriors
F21V	Functional features or details of lighting devices or systems thereof; structural combinations of lighting devices with other articles, not otherwise provided for
F21W	Indexing scheme associated with subclasses f21k, f21l, f21s and f21v, relating to uses or applications of lighting devices or systems
F21Y	Indexing scheme associated with subclasses f21k, f21l, f21s and f21v, relating to the form or the kind of the light sources or of the colour of the light emitted
F24B	Domestic stoves or ranges for solid fuels (for solid fuels in combination with gaseous fuels, liquid fuels or other kinds of energy supply f24c0001020000); implements for use in connection with stoves or ranges
F24C	Domestic stoves or ranges (exclusively for solid fuels f24b); details of domestic stoves or ranges, of general application
F24D	Domestic- or space-heating systems, e.g. Central heating systems; domestic hot-water supply systems; elements or components therefor (using steam or condensate extracted or exhausted from steam engine plants for heating purposes f01k0017020000)
F24F	Air-conditioning; air-humidification; ventilation; use of air currents for screening (removing dirt or fumes from areas where they are produced b08b0015000000; vertical ducts for carrying away waste gases from buildings e04f0017020000; tops for chimneys or ventilating shafts, terminals for flues f23l0017020000)
F24H	Fluid heaters, e.g. Water or air heaters, having heat-generating means, e.g. Heat pumps, in general (steam generation f22)
F25B	Refrigeration machines, plants or systems; combined heating and refrigeration systems; heat pump systems
F25D	Refrigerators; cold rooms; ice-boxes; cooling or freezing apparatus not otherwise provided for (refrigerated showcases a47f0003040000;thermally-insulated vessels for domestic use a47j0041000000;refrigerated vehicles, see the appropriate subclasses of classes b60-b64; containers with thermal insulation in general b65d0081380000;heat-transfer, heat-exchange or heat-storage materials, e.g. Refrigerants, or materials for the production of heat or cold by chemical reactions other than by combustion c09k0005000000;thermally-insulated vessels for liquefied or solidified gases f17c;air-conditioning or air-humidification f24f;refrigeration machines, plants, or systems f25b;cooling of instruments or comparable apparatus without refrigeration g12b;cooling of engines or pumps, see the relevant classes)
F28B	Steam or vapour condensers (condensation of vapours b01d0005000000;condensation during pretreatment of gases prior to electrostatic precipitation of dispersed particles b03c0003014000;steam engine plants having condensers f01k;liquefaction of gases f25j;details of heat-exchange or heat-transfer arrangements of general application f28f)
F28C	Heat-exchange apparatus, not provided for in another subclass, in which the heat-exchange media come into direct contact without chemical interaction (heat-transfer, heat-exchange or heat-storage materials c09k0005000000;â fluid heaters having heat generating means f24h;with an intermediate heat-transfer medium coming into direct contact with heat-exchange media f28d0015000000-f28d0019000000;details of heat-exchange apparatus of general application f28f)
F28D	Heat-exchange apparatus, not provided for in another subclass, in which the heat-exchange media do not come into direct contact (heat-transfer, heat-exchange or heat-storage materials c09k0005000000;â fluid heaters having heat generating means and heat transferring means f24h;furnaces f27;details of heat-exchange apparatus of general application f28f); heat storage plants or apparatus in general
F28F	Details of heat-exchange or heat-transfer apparatus, of general application (heat-transfer, heat-exchange or heat-storage materials c09k0005000000;water or air traps, air venting f16)
F28G	Cleaning of internal or external surfaces of heat-exchange or heat-transfer conduits, e.g. Water tubes of boilers (cleaning pipes or tubes in general b08b0009020000;devices or arrangements for removing water, minerals, or sludge from boilers while the boiler is in operation, or which remain in position while the boiler is in operation, or are specifically adapted to boilers without any other utility f22b0037480000;removal or treatment of combustion products or combustion residues f23j;removing ice from heat-exchange apparatus f28f0017000000)
H05B	Electric heating; electric light sources not otherwise provided for; circuit arrangements for electric light sources, in general