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Construction Value Chains and Their Productivity Growth

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Abstract

The construction industry has suffered from low 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 with data from the World Input–Output and EU KLEMS databases. We decompose construction-related value-added and productivity contributions to the construction industry and the rest of the value chain, and show that the traditional focus on the construction industry is restrictive. There is a substantial amount of construction-related value-added generated in other industries, and the productivity growth in the construction value chains has, for the most part, been seen in them. 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 value chains typically suffer from low efficiency in the use of information technology.

Tiivistelmä

Rakentamisen arvoketjut ja niiden tuottavuus

Rakennusala on kärsinyt heikosta tuottavuuskasvusta viime vuosikymmeninä. Tässä tutkimuksessa pureudutaan tuottavuuden mittaamisen yhteen keskeiseen haasteeseen, eli tuotannon jakautumiseen monimutkaisiin arvoketjuihin. Erityisesti rakennusala on mittaamisen kannalta vaativa, sillä työmaalla tapahtuvassa rakentamisessa luodaan nykyisin vain murto-osa rakentamisen arvosta. Koska rakennusalalla on kansantaloudessa erittäin merkittävä rooli, on tärkeätä ymmärtää paremmin tuottavuuden heikon kehityksen ja arvoketjujen välisiä yhteyksiä.

Tarkastelemme tutkimuksessamme rakentamisen tuottavuutta mitaten ja vertaillen kahdentoista Euroopan maan rakentamisen arvoketjuja. Menetelmämme kykenee arvioimaan rakentamisen tuottavuuskehitystä aiempaa laajemmin, ottaen huomioon myös arvoketjussa tapahtuvat muutokset. Lähestymistapa on ainutlaatuinen, ja se avaa uusia näkökulmia sekä kotimaiseen arvonluontitarkasteluun että globaaliin kilpailukykyvertailuun. Hyödynnämme tarkastelussa maailman panos-tuotos- ja EU KLEMS -tietokantoja.

Tutkimuksessa jaottelemme rakentamisessa syntyvän arvonlisän ja tuottavuuskasvun rakennusalalle ja muuhun arvoketjuun. Osoitamme, että perinteinen keskittyminen pelkkään rakennusalaan on ongelmallinen. Muussa arvoketjussa syntyy huomattava määrä rakentamiseen liittyvää arvonlisää, ja rakentamisen arvoketjujen tuottavuuden kasvu syntyy suurimmaksi osaksi juuri näissä muun kuin varsinaisen rakennusalan arvoketjun osissa.

Osoitamme myös, että rakentamiseen liittyvien patenttien ja arvoketjujen kokonaistuottavuuskehityksen välillä on vahva ja pitkävaikutteinen suhde. Rakennusalan tulevaisuuden kannalta mielenkiintoista on havaintomme, että arvoketjujen tuottavuuskehitys kärsii tehottomasta informaatioteknologian käytöstä – digiloikka saattaa johtaa tulevaisuuden rakennusalalla myös tuottavuusloikkaan!

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Keywords: Construction, Productivity, Global value chains, Organization of production, Production management, Industrial structure and structural change

Asiasanat: Rakentaminen, Tuottavuus, Globaalit arvoketjut, Tuotannon organisointi, Tuotannon johtaminen, Toimialarakenne, Rakennemuutos

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1. Introduction

Construction industries are significant contributors to economic activity in most countries. On average, they account for around 6% to 9% of an economy's gross domestic product (Arditi and Mochtar, 2000). However, the productivity of 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 either no productivity growth or even declining productivity in the European construction industries over a period of several decades (Economist, 2017). This controversial finding leaves open many questions about both the origins of the poor performance and the quality of the underlying productivity statistics.

This paper deals with a key challenge of the analysis: the fragmentation of the construction sector[1] in complex value chains. Only a fraction of construction value creation is nowadays done by the construction industry on-site, and a focus on its productivity hides substantial networks of technologically progressive manufacturing and business services. Thus, a value chain perspective on the construction sector is important in providing further understanding about its organization and performance, as it makes more visible both the substantial role of the upstream industries as well as technology and knowledge investments as a source of productivity growth in the value chain as a whole.

Our work builds on a novel decomposition of the value-added contents of the outputs and contributions of the construction industry and other sectors in the upstream value chain. We use the World Input–Output Database (WIOD) and the method recently suggested by Los et al. (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.[2] Furthermore, we studied the productivity growth contributions of the industries that participate in the value chains. In particular, we used the data concerning the generated value-add in the value chains to weight the corresponding industry-level productivity growth measurements in the EU KLEMS database and account for their contribution of the value-added factor in growth (see, e.g., Wolff, 1994, and Timmer, 2017).

Our analysis shows that the focus on the construction industry is restrictive. 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 outside the construction industry, a finding that is common in all observed value chains. The rest of the value added is generated by other industries involving both manufacturing and business services. We find that the role of the business service sector, in particular, is important and increased in the years 2001 to 2014. Moreover, the productivity growth in the

[1] In what follows, we refer to all construction-related economic activity, including and beyond the construction industry as the construction sector.
[2] AUT, BEL, CZE, DEU, DNK, ESP, FIN, FRA, GBR, ITA, NLD, and SWE.

construction value chains has, for the most part, occurred in the upstream part of the value chain, while the role of the construction industry is weak or even negative. This finding suggests that the focus on the construction industry will lead to a bias downward in the productivity of construction activities. We also show that there is a strong long-term relationship between construction-related patents and the improvement of total factor productivity (TFP) in a value chain by using a panel vector error correction model.

This paper is organized as follows. In Section 2, we review the literature. Section 3 introduces the methodology, while Section 4 studies the composition of the construction value chain. Section 5 discusses the productivity growth in the value chain, and Section 6 considers the effects of patents and information technology in the value chain. Section 7 concludes.

2. Literature

This paper contributes to several strands of the literature. First, our paper provides a novel way to construct the role of different industries by means of manipulating the global input–output data that is more commonly used in an international trade context (Los et al., 2016; Ali-Yrkkö and Kuusi, 2017, 2019). It is one of few attempts to capture the full economic scope of the construction sector beyond the contribution of the industry. Previously, Squicciarini and Asikainen (2011) used a discretionary classification of the construction sector to core and supporting industries, and 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. The evidence that they produced suggests that indicators measuring the 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. More typically, however, the construction value chains are considered at the level of individual projects (see, e.g., Ali-Yrkkö et al., 2016).

Another paper discussed a study of the links between the difficulties of the construction industries with capturing their productivity potential and the qualities of their value chains. The literature suggests that the 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 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 many 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 sector. These factors tend to keep investments at low levels (Economist, 2017). Moreover, due to the complex nature of construction projects they 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, avoiding the generation of bigger, more productive companies. Construction projects often have many subcontractors, and each is keen to maximize profit rather than collaborate to contain costs.

All in all, the fragmentation often results in low formalization, low coupling and low specificity of the value chains (Ketokivi et al., 2017). That is, the 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 the decisions about one sub-entity are typically made independently of decisions about other sub-entities.

Naoum´s 2016 study revealed that the rate of labor 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 labor 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; however, problems arise due to the time lag for a new technology to reach its full potential.

These findings correspond with the literature regarding more general productivity. A few studies have shown that the impact of ICT on an industry level plays only a limited role as a source of productivity growth. This finding is reported by, among others, Stiroh (2002a), Draca et al. (2006), and Inklaar et al. (2008). Complementary innovations in organizations are often needed to foster successful adaptation of a new technology (Bresnahan et al., 2002). Consistently, O'Mahony and Vecchi (2005), Oulton and Srinivasan (2005), and Venturini (2009) report a larger long-term effect. We studied how patents have improved productivity alongside a growing body of literature connecting TFP and patents (see, e.g., Romer, 1990; Grossman and Helpman, 1994; Madsen, 2008; Coe et al., 2009). It is notable that innovativeness is also tightly linked with the adoption of new technology.

The challenges of efficient ICT investment may become particularly large when its effects are considered jointly for the whole value chain. The 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 the 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 and flexible 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 specificities of measurement of construction industry productivity. The introduction of the EU KLEMS database has made it easier to perform comparative analyses at the industry level. A few papers have analyzed the productivity dynamics (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 by using detailed US data that productivity growth may be somewhat greater than previous results suggest. On the other hand, there have been attempts to include details of project-level information to better account for the increase in the quality of outputs (Sezer and Bröchner, 2014). One conclusion is that it should be possible to use the increasing volume of performance indicator data collected for construction projects, and that may improve the quality of the productivity statistics, but so far, this approach has been infeasible due to resource constraints.

Due to statistical problems and the heterogeneity of data collection practices, we acknowledge that one should be careful in making comparisons of productivity levels across countries (Vogl and Abdel-Wahab, 2015). Rather, we focus on explaining productivity growth statistics to analyze changes in value chains over time. Moreover, due to the short-term impacts of the business cycles (Abbott and Carson, 2012), we consider the average behavior of the sector over the different phases of the most recent business cycle (2001–2014).

3. Methodology

We studied the productivity growth by combining the 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.

3.1. Data

In our analyses, we used the 2016 release of the WIOD database (Timmer et al., 2015, 2016).[3] 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 world for the period 2000–2014.[4] Together, the countries cover more than 85% 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).

[3] http://www.wiod.org/home

[4] 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).

This research combined the WIOD database and the EU KLEMS database (2017 release, www.euklems.net). EU KLEMS data were constructed to provide internationally comparable and consistent time series on outputs, inputs, and productivity by industry (Jäger, 2017). The EU KLEMS database covers EU-25 as well as several other industrialized countries. In general, data for 1970–2005 are available for the old EU-15 nations as well as for the US, Australia, and Japan. Series from 1995 onward are available for the new EU member states that joined the EU on May 1, 2004. Due to data limitations, the coverage 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.

3.2. Measurement of the value-added contribution in the value chain

We applied a measurement framework for the decomposition of value-add in the construction value chain grounded on hypothetical extraction, a parsimonious mathematical technique based on an input–output representation of the global economy (Los et al., 2016). This approach has clear economic intuition and can easily be applied to the data. It compares the actual GDP in a country with a hypothetical GDP in cases where there are no production activities related to construction. The difference is defined as the value added of construction activities. In what follows, we refer to input–output tables in a certain year *t*, while abstract from the further use of time indices.

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*, $\boldsymbol{F^s}$, 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:

$$\boldsymbol{A} = \begin{bmatrix} \boldsymbol{A_{F^sF^s}} & \boldsymbol{A_{F^sr}} \\ \boldsymbol{A_{rF^s}} & \boldsymbol{A_{rr}} \end{bmatrix} \tag{1}$$

Matrix **A** contains the input coefficients a_{ij}, which give the value units of intermediate goods from industry *i* required to produce one value unit of gross output in industry *j*. $\boldsymbol{A_{F^sF^s}}$ represents the purchase requirements of the construction industry from itself in country *s*, while $\boldsymbol{A_{rF^s}}$ 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

$$\boldsymbol{Y} = \begin{bmatrix} \boldsymbol{y_{F^sF^s}} & \boldsymbol{y_{F^sr}} \\ \boldsymbol{y_{rF^s}} & \boldsymbol{y_{rr}} \end{bmatrix}, \tag{2}$$

in which the vectors $\boldsymbol{y_{F^sF^s}}$ and $\boldsymbol{y_{F^sr}}$ 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.

For any industry–country pair *j*, the ratios of value added to gross output is contained in row vector $\boldsymbol{v_j}$. The length of this vector equals the number of all industries in all countries with the value-added ratio for industry–country *j* as element $\bar{\boldsymbol{v}}_j$ and zeros elsewhere: $\boldsymbol{v}_j$=$[\mathbf{0}\ \bar{\boldsymbol{v}}_j\ \mathbf{0}]$. The value added in country–industry pair $\boldsymbol{VA_j}$ then equals

$$\boldsymbol{VA_j} = \boldsymbol{v_j}(\boldsymbol{I}-\boldsymbol{A})^{-1}\boldsymbol{Y} * \boldsymbol{i}, \tag{3}$$

in which ***i*** is a column vector where all elements are united, implying that it sums the two elements in each of the rows of Matrix ***Y***. The element $(\boldsymbol{I}-\boldsymbol{A})^{-1}$ is the well-known Leontief inverse, in which ***I*** is the identity matrix of appropriate dimensions. The expression is key to accounting for the complexity of construction value chains. $\boldsymbol{VA_j}$ can be interpreted as the limiting value of the infinitely long sum of value-added 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 $\boldsymbol{A_{F^s r}} = \mathbf{0},$ yielding

$$\boldsymbol{A}^*(\boldsymbol{F^s}) = \begin{bmatrix} \boldsymbol{A_{F^sF^s}} & \mathbf{0} \\ \boldsymbol{A_{rF^s}} & \boldsymbol{A_{rr}} \end{bmatrix}, \tag{4}$$

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

$$\boldsymbol{Y}^*(\boldsymbol{F^s}) = \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \boldsymbol{y_{rF^s}} & \boldsymbol{y_{rr}} \end{bmatrix}. \tag{5}$$

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

$$\boldsymbol{VA}_j^*(\boldsymbol{F^s}) = \boldsymbol{v_j}(\boldsymbol{I}-\boldsymbol{A}^*(\boldsymbol{F^s}))^{-1}\boldsymbol{Y}^*(\boldsymbol{F^s}) * \boldsymbol{i} \tag{6}$$

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:

$$\boldsymbol{\Delta VA_j}(\boldsymbol{F^s}) = \boldsymbol{VA_j} - \boldsymbol{VA}_j^*(\boldsymbol{F^s}), \tag{7}$$

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

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

3.3. Factor-based productivity contributions to construction output

We will next discuss our approach to measuring the productivity contributions of different sectors. It is good to start by reviewing the classical KLEMS productivity approach that is commonly used to analyze the productivity of the construction industry. In an approach that builds on Jorgenson et al. (1987), gross output production function includes two groups of factor inputs, capital (K) and labor (L), and three groups 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, modeling 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 such that analyses based on industry value added have to rely on strong assumptions of separability. As conditions that are jointly necessary and sufficient for the existence of sectoral value-added functions are typically rejected, intermediate inputs should be treated symmetrically with factor inputs in the productivity analysis. Thus, the robustness of the KLEMS approach becomes increasingly dependent on proper price measurement of intermediate inputs. 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).

What is proposed here is to analyze a production function (F) where final output is produced based on factor inputs only, including both domestic and foreign factors, similar to Wolff (1994) and Timmer (2017). Using the information from the exclusion method, the flow of intermediate inputs will be netted out such that the production function of a final good can be written in terms of factor inputs only. They are located in the industry where the last stage of production takes place, as well as in other industries (domestic and foreign) contributing to earlier stages of production.

Formally, let F be a translog production function for the construction aggregate product: $f = F(\mathbf{\Lambda}, \mathbf{K}, T)$, where $\mathbf{\Lambda}$ is the column vector of labor requirements for production, $\mathbf{K}$ is similarly a column vector of capital requirements, and T denotes technology. The factor requirements were measured by using industry-specific input-to-value-added ratios. Under the standard assumptions of constant returns to scale and perfect input markets, we can define productivity growth in the global value chains of construction by the weighted rate of decline of its total labor and capital requirements:

$$\frac{\delta \pi}{\delta t}(\boldsymbol{F^s}) = -\overline{\boldsymbol{\alpha^L}}(\boldsymbol{F^s})\frac{\delta \mathbf{\Lambda}}{\delta t} - \overline{\boldsymbol{\alpha^K}}(\boldsymbol{F^s})\frac{\delta \mathbf{K}}{\delta t}, \tag{8}$$

where $\frac{\delta\Lambda}{\delta t}$ and $\frac{\delta\mathrm{K}}{\delta t}$ are vectors of the changes in the labor and capital requirements, respectively, and $\boldsymbol{\alpha^L}$ and $\boldsymbol{\alpha^K}$ are the weights given by a (row) vector of value shares with elements reflecting the costs of labor and capital from all country sectors used in the production of one unit of construction product, respectively .

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

$$\boldsymbol{\alpha_j^L(F^s) = \Delta VA_j(F^s) * \alpha_j^{VA,L}} \quad (9)$$

$$\boldsymbol{\alpha_j^K(F^s) = \Delta VA_j(F^s) * \alpha_j^{VA,K}}, \quad (10)$$

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 $\boldsymbol{v_j = \bar{v}_j}$ and zero otherwise, while the counterfactual without the construction sector is defined by setting $\boldsymbol{A = A^*(F^S)}$ and $\boldsymbol{Y = Y^*(F^S)}$**,** as defined in the previous subsection. $\alpha_j^{VA,L}$ and $\alpha_j^{VA,K}$ are the KLEMS-based measures of the labor 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 $\boldsymbol{\overline{\alpha^L} = (\alpha_{-1}^L + \alpha^L)/2}$ and $\boldsymbol{\overline{\alpha^K} = (\alpha_{-1}^K + \alpha^K)/2}$**.** Here, we refer to the year t ($\boldsymbol{\alpha}$) and year *t*-1 shares ($\boldsymbol{\alpha_{-1}}$).

Finally, the productivity decomposition into components of the different industries and the TFP arose. In discrete time, the resource use vectors of all industries are $\frac{\delta\Lambda}{\delta t} = \boldsymbol{\Delta\log(\Lambda_t)}$ and $\frac{\delta\mathrm{K}}{\delta t} = \boldsymbol{\Delta\log(\mathrm{K}_t)}$, where $\boldsymbol{L_t}, \boldsymbol{K_t}$, and $\boldsymbol{Y_t}$ are the labor and capital inputs, and the industry's gross outputs, respectively. The decomposition of the real gross output growth in the construction industry (Y_{t,F^s}) into the contributions of factors and the TFP (as residual) is

$$\boldsymbol{\Delta\log(Y_{t,F^s}) = \overline{\alpha^L}(F^s)\Delta\log(\Lambda_t) + \overline{\alpha^K}(F^s)\Delta\log(\mathrm{K}_t) + \Delta\pi(F^s).} \quad (11)$$

To provide some more detail of the analysis, we further decomposed labor growth contribution into components arising from the change in the number of hours and change in the composition of the labor force. Labor 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 labor categories (3 × 2 × 3 types). It is assumed that service flows are proportional to the hours worked, and wages reflect the relative marginal productivity in labor (see, Jäger, 2017). This allowed us to decompose the labor input growth into contributions of labor composition ***LC*** and number of hours ***H***.

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.

In the empirical analysis, we can account for the productivity growth of industries that represents a large majority of the total value added generated in the value chain (on average, 86%). This provides a relatively robust view of the productivity in the value chains. In what follows, we assumed that the input contributions as well as the TFP growth in the missing data are zero. Therefore, our results provide the lower bound of the actual productivity impact of the construction value chains.

4. The role of services has increased in construction value chains

We first analyzed the industry decomposition 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.

Table 1 Value-add shares of different sectors in construction value chains. 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).

	Share of the value chain value VA in 2014 (%)				**Change of the share btw. 2000 and 2014 (pps)**			
	Primary	Manufacturing	Construction	Services	Primary	Manufacturing	Construction	Services
AUT	3 %	16 %	53 %	28 %	1.1	0.0	-6.1	4.9
BEL	4 %	16 %	43 %	37 %	0.7	-1.0	-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	1.0	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 %	1.0	-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	-2.0	-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**

We found that, on average, the construction sector only accounts for roughly 48% of the value-add generated in the value chain. The next largest contributing sector is the services sector, which generates 34% of the value-add, while manufacturing and primary production generate 15% and 3%, respectively. The results also suggest that there are similarities in the organization of construction activities across countries. For example, the share of the construction industry varies within a limited interval between 41% and 56% of total value added. The biggest shares of the construction industry were measured from the UK (56%), Spain (53%), and Austria (53%), while the smallest shares were measured from Denmark (41%), Belgium (43%), and the Czech Republic (44%).

Over time, there have been some changes in the shares. Over the years 2000 to 2014, the average share of the service sector increased roughly 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 the reallocation of tasks in 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 pps); (2) financial and insurance activities (+ 0.5 pps); and (3) wholesale trade, except of motor vehicles and motorcycles (+0.4 pps).

5. Productivity growth in the construction value chain is higher than in the construction industry

We will next analyze the origins of productivity growth in the value chains by using the factor-based accounting of the industry contributions using the methodology that we discussed more thoroughly in Section 2.

Based on our baseline findings, the construction value chain is rather different from the construction industry in terms of capital intensity and productivity growth (see Table 2). The average capital intensity (35%) in the value chain is 13 pps greater than that of the construction industry (22%) for the measured part of the value chain. This suggests that the return of production capital per unit of production is higher in value chains, indicating that either there is more capital or the production is more profitable.

The average labor productivity growth as measured by the contributions of capital and labor quality deepening and TFP has been 0.6% per year, while in the construction industry, the growth in these components has been negligible. The difference is explained by many factors: better performance of TFP, capital deepening, and increases in the quality of labor, while TFP has been the single greatest contributing factor. This finding suggests that the benefits of the organization of construction activities in global value chains may be underestimated when traditional productivity statistics are used.

Our findings, of course, hide a considerable amount of heterogeneity in country-level construction activities. At the high end of productivity growth, the Belgium construction sector with its marine construction activities is a well-known success story (Economist, 2017). The improvements in productivity clearly seen in our data can be traced to the mechanical improvements of tools, increased measurement and use of ICT, and introduction of modular building. The cases of Spain and the Czech Republic are quite different. In those countries, the productivity improvements are associated with large reductions of the labor 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 of productivity growth, the construction sectors in Italy and France are well known for their poor productivity performance. What is interesting, however, is that in the case of France, our accounting of the value chain productivity at least partly offset the poor developments of the industry, suggesting that there had been a shift of productivity growth toward the upstream that was not seen in the traditional statistics.

Table 2 Comparison of the construction value chain and the construction industry Note: TFP is the total-factor productivity, IT is information and communications technology capital stock, and NIT is the traditional capital stock.

	Construction value chain						
	Capital share (a)	*Productivity growth excluding hours: b = c+d+e+f*	TFP growth contribution (c)	IT growth contribution (d)	NIT growth contribution (e)	Labor composition contribution (f)	Hours contribution (g)
AUT	41 %	*0.6*	0.0	0.1	0.4	0.1	0.1
BEL	39 %	*1.3*	0.0	0.3	0.7	0.2	0.4
CZE	43 %	*1.8*	0.1	0.0	1.3	0.4	−0.5
DEU	30 %	*0.7*	0.1	0.1	0.0	0.5	−1.3
DNK	29 %	*0.6*	−0.3	0.1	0.3	0.6	−0.2
ESP	39 %	*2.1*	1.2	0.0	0.7	0.3	−2.1
FIN	33 %	*0.3*	−0.1	0.1	0.4	−0.1	0.1
FRA	32 %	*0.1*	−0.7	0.0	0.5	0.4	0.4
GBR	24 %	*−0.1*	−1.1	0.1	0.3	0.6	0.1
ITA	38 %	*−1.1*	−1.3	−0.1	0.1	0.2	−0.8
NLD	29 %	*0.7*	−0.5	0.2	0.1	0.8	−1.3
SWE	39 %	*0.5*	−0.8	0.2	1.3	−0.1	1.0
Average	**35 %**	***0.6***	***−0.3***	***0.2***	***0.7***	***0.3***	***−0.3***

	Construction industry						
	Capital share (a)	*Productivity growth excluding hours: b = c+d+e+f*	TFP growth contribution (c)	IT growth contribution (d)	NIT growth contribution (e)	Labor composition contribution (f)	Hours contribution (g)
AUT	36 %	*−1.0*	−1.0	0.1	0.1	−0.1	0.0
BEL	39 %	*2.0*	0.2	0.2	1.4	0.2	0.3
CZE	30 %	*1.3*	−0.4	0.1	1.1	0.5	−0.4
DEU	5 %	*0.0*	−0.3	0.0	0.1	0.2	−1.3
DNK	15 %	*1.1*	−0.1	0.1	0.1	1.1	−0.4
ESP	38 %	*−0.2*	−1.8	0.0	1.1	0.5	−2.8
FIN	9 %	*−0.2*	−0.6	0.0	0.4	−0.1	0.5
FRA	18 %	*−1.5*	−1.9	0.1	0.2	0.2	1.1
GBR	10 %	*0.3*	−0.1	0.0	0.1	0.3	0.6
ITA	27 %	*−1.1*	−1.5	0.0	0.3	0.1	−0.3
NLD	1 %	*0.2*	−0.4	−0.1	0.0	0.7	−1.2
SWE	33 %	*−0.7*	−1.8	0.0	1.5	−0.4	1.2
Average	**22 %**	***0.0***	***−0.8***	***0.2***	***0.7***	***0.3***	***−0.3***

We further decomposed the productivity growth of the value chain to the contributions of the construction industry and the upstream of the value chain (Table 3). In the case of the productivity growth contribution to the inputs, it is straightforward. However, the problem is that the TFP contribution of the total value chain cannot be allocated directly to either part of the value chain. One avenue forward suggested by Timmer (2017) is to assume that the TFP is better estimated for the upstream part of the value chain, so that the traditionally measured TFP of the upstream (weighted by the value-added shares of the industries in the value chain) characterizes correctly the role of TFP growth in the upstream. Then the role of the construction sector becomes apparent as the residual.

When we measure the contribution of the upstream TFP growth in this manner, shown in Table 3, the results suggested that upstream contributed substantially more to the overall productivity growth of the construction value chain. The productivity growth contribution of upstream was roughly 0.8 percentage points per year, while the construction industry's contribution was −0.2 percentage points. This is mostly due to differentiated TFP dynamics.

What explains 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 productivity tasks are shifted to the upstream part of the value chain, the remaining industry tasks are less productive, but through reallocation of the tasks, the productivity of the total value chain has, nevertheless, increased. Having said that, however, the results may partly reflect measurement problems. It could be that the growth of the output volume index may be underestimated, as was suggested by previous papers in the literature. Another contributing factor to low productivity growth may have been the recent, strong economic downturn.

We also studied the role of the value chain by the origin of the supplier (Table 4). In particular, we divided the chain into the components that reflect productivity growth in the domestic and foreign parts of the value chain. We found that the role of the foreign part was not dominant in productivity dynamics. In terms of the capital deepening and improvements of the labor composition, the foreign part of the chain contributed only roughly 0.2 pps per year to the overall productivity growth, whereas the same number was 1.2 pps for the domestic part of the value chain. However, the foreign upstream becomes somewhat more important if the EU KLEMS based TFP is used to quantify its contribution to overall efficiency growth. That is because when the domestic TFP is measured as a residual between the overall TFP and the foreign EU KLEMS based component, almost all of the negative TFP dynamics in the sector are left to be explained by the domestic part of the value chain.

Table 3 Decomposition of the construction value chain to the industry and the upstream components Note: TFP is the total-factor productivity, IT is information and communications technology capital stock, and NIT is the traditional capital stock.

	Upstream part of the value chain							
	VA share (a)	Cap share (b)	Productivity growth excluding hours: c = d+e+f+g	TFP growth contribution (d)	IT growth contribution (e)	NIT growth contribution (f)	Labor composition contribution (g)	Hours contribution (h)
AUT	45 %	43 %	0.9	0.5	0.1	0.3	0.1	0.2
BEL	54 %	42 %	1.0	0.5	0.2	0.1	0.1	0.3
CZE	56 %	49 %	1.8	1.0	−0.1	0.7	0.1	−0.2
DEU	52 %	45 %	0.5	0.4	0.0	0.0	0.0	−0.3
DNK	59 %	37 %	0.7	0.3	0.1	0.2	0.1	0.0
ESP	46 %	40 %	0.5	0.4	0.0	0.1	0.0	−0.5
FIN	56 %	41 %	0.6	0.5	0.1	0.0	0.0	−0.2
FRA	51 %	37 %	0.9	0.4	0.0	0.3	0.1	0.1
GBR	42 %	34 %	1.1	0.6	0.1	0.2	0.2	0.1
ITA	53 %	44 %	0.0	0.1	−0.1	0.0	0.0	−0.5
NLD	51 %	41 %	0.5	0.3	0.0	0.0	0.1	−0.4
SWE	49 %	44 %	1.5	0.7	0.1	0.5	0.1	0.4
Average	**51 %**	**41 %**	**0.8**	**0.5**	**0.1**	**0.2**	**0.1**	**−0.1**

	Construction industry part of the value chain							
	VA share (a)	Cap share (b)	*Productivity growth excluding hours: c = d+e+f+g*	TFP growth contribution (d)	IT growth contribution (e)	NIT growth contribution (f)	Labor composition contribution (g)	Hours contribution (h)
AUT	55 %	38 %	−0.3	−0.5	0.0	0.1	0.0	−0.1
BEL	46 %	35 %	0.4	−0.4	0.1	0.6	0.1	0.1
CZE	44 %	36 %	0.0	−1.0	0.1	0.6	0.3	−0.3
DEU	48 %	13 %	0.2	−0.2	0.1	0.0	0.4	−0.9
DNK	41 %	17 %	−0.1	−0.6	0.0	0.1	0.4	−0.2
ESP	54 %	38 %	1.7	0.8	0.0	0.6	0.3	−1.6
FIN	44 %	23 %	−0.3	−0.6	0.0	0.4	−0.1	0.3
FRA	49 %	26 %	−0.8	−1.2	0.0	0.1	0.2	0.3
GBR	58 %	17 %	−1.2	−1.7	0.0	0.1	0.4	0.0
ITA	47 %	31 %	−1.1	−1.4	0.0	0.1	0.2	−0.3
NLD	49 %	16 %	0.1	−0.8	0.2	0.1	0.7	−0.9
SWE	51 %	34 %	−1.0	−1.5	0.0	0.8	−0.3	0.7
Average	**49 %**	**27 %**	**−0.2**	**−0.8**	**0.1**	**0.3**	**0.2**	**−0.2**

Table 4. Decomposition of the construction value chains to the domestic and foreign components. Note: TFP is the total-factor productivity, IT is information and communications technology capital stock, and NIT is the traditional capital stock.

	Foreign part of the value chain							
	VA share (a)	Cap share (b)	*Productivity growth excluding hours: c = d+e+f+g*	TFP growth contribution (d)	IT growth contribution (e)	NIT growth contribution (f)	Labor composition contribution (g)	Hours contribution (h)
AUT	20 %	42 %	*0.3*	0.1	0.0	0.1	0.0	0.1
BEL	29 %	44 %	*0.4*	0.2	0.2	0.0	0.1	0.3
CZE	23 %	44 %	*0.3*	0.2	0.0	0.1	0.0	0.1
DEU	15 %	46 %	*0.2*	0.1	0.1	−0.1	0.0	0.0
DNK	27 %	43 %	*0.3*	0.1	0.1	0.1	0.0	0.1
ESP	12 %	43 %	*0.1*	0.1	0.0	0.0	0.0	−0.1
FIN	21 %	46 %	*0.3*	0.1	0.0	0.1	0.0	0.0
FRA	16 %	43 %	*0.2*	0.1	0.0	0.1	0.0	0.1
GBR	12 %	46 %	*0.2*	0.1	0.0	0.1	0.0	0.1
ITA	12 %	44 %	*0.1*	0.1	0.0	0.0	0.0	−0.1
NLD	25 %	43 %	*0.3*	0.2	0.0	0.0	0.0	0.0
SWE	20 %	44 %	*0.3*	0.1	0.1	0.1	0.0	0.0
Average	**19 %**	**44 %**	***0.3***	**0.1**	**0.1**	**0.1**	**0.0**	**0.0**

6. Innovations contribute to long-term TFP, while the efficiency of IT adoption is a problem

Our measure of the TFP for the whole construction sector reflected the overall efficiency of several industries operating in interaction. Thus, it is interesting to also relate this efficiency growth to the innovativeness within the sector. This may help to better understand the determinants of productivity growth of construction activities.

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. In particular, we summed up the total number of patents for a wide variety of different patent classes, including innovations in materials, construction technology, lighting, electricity, and air-conditioning systems (see Appendix). Importantly, these innovations are made not only by the construction industry but also possibly by other industries in the value chain.[5]

In what follows, we resorted to panel data estimation by using yearly data and the value chains of different countries as panel units, and we estimated a panel error correction model. The model allowed us to separately study the short-term dynamics and long-term equilibrium relationship between innovation and the TFP. By this, we aimed to isolate the short-term frictions and implementation lags from the potential effects of innovativeness and focused on the full potential level of knowledge capital stock (see, e.g., O'Mahony and Vecchi, 2005).

We used the so-called mean group estimator by Pesaran et al. (1999) that estimates a common long-term relationship for each construction value chain. We first studied the time series properties of our variables of interest. We found that the index of TFP, the cumulative capital and labor contributions (constructed by summing the yearly log-point contribution terms), and the level of patent intensity were trend stationary, and they were cointegrated of order 1.[6] Accordingly, we constructed the error correction form of the relationship.

We will next formally introduce a long-run relationship between TFP and the different input growth contributions. As before, let us denote TFP as π_t and the contributions of labor, capital, and patents as c^{CAP}, c^{LAB}, and c^{PAT}, respectively. Then, the relationship is for the value chain *i* = 1,2,…,12 and time period *t* = 2001,2002,…,2014.

[5] Because TFP growth measures the relative 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.

[6] By using Im–Pesaran–Shin and Fisher-type tests in Stata (xtunitroot package), we found that the zero hypotheses of all panels having unit roots could not 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 tested 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.

$$\boldsymbol{\pi_{it} = \theta_{iIT} c_{it}^{LAB} + \theta_{iNIT} c_{it}^{CAP} + \theta_{iLC} c_{it}^{PAT} + \mu_i + \epsilon_{it}} \quad (12)$$

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

$$\boldsymbol{\Delta\pi_t = \phi_i(\pi_{it-1} - \theta_{i0} - \theta_{iLAB} c_{it}^{LAB} - \theta_{iCAP} c_{it}^{CAP} - \theta_{iPAT} c_{it}^{PAT}) + \delta_{iLAB} \Delta c_{it}^{LAB} +}$$
$$\boldsymbol{\delta_{iCAP} \Delta c_{it}^{CAP} + \delta_{iPAT} \Delta c_{it}^{PAT} + \delta_{it} t + \delta_{it} t + \delta_{it}^{SQ} t^2 + \epsilon_{it},} \quad (13)$$

where the first term is the long-run cointegration relationship between TFP and input contributions. θ's denote the long-term elasticity of different factor contributions with TFP, δ's are the short-term elasticities, and ϕ_i is the error correction speed of adjustment parameter. The key parameters of interest are the long-term elasticity of patent intensity θ_{iPAT} and the error correction speed of adjustment.

*Table 5 Results of the error correction model analysis of the link between inputs and total factor productivity (TFP); Note: The confidence levels are *p < .05; **p < .01; ***p < .001*

	Construction value chain			Construction industry		
Dependent variable:	(a) Only patents	(b) Inputs included	(c) IT and NIT separately	(a) Only patents	(b) Inputs included	(c) IT and NIT separately
Pooled mean group normalized cointegrating vector						
Patent intensity	0.526***	0.321***	0.398***	0.677***	0.107***	0.127***
(standard error)	(0.131)	(0.046)	(0.049)	(0.141)	(0.024)	(0.015)
IT comp. contribution			−1.969***			−7.092***
(standard error)			(0.481)			(1.788)
NIT comp. contribution			−0.321			−8.003***
Capital comp. contribution		0.168			−5.553***	
Labor comp. contribution		−0.12	−0.036		−0.008	0.755***
The average short-run dynamic coefficients						
Δ Patent intensity	0.056	−0.090**	−0.094*	0.053	0.037	0.025
Δ IT comp. contribution			0.031			−1.932
Δ NIT comp. contribution			−0.48			3.339*
Δ Capital comp. contribution		−0.63			3.078*	
Δ Labor comp. contribution		0.684*	0.548*		0.032	−0.25
Linear time trend comp.	3.731	0.701	1.933	−1.474	2.154	2.093
Quadratic time trend comp.	−0.001	0	0	0	−0.001	−0.001
Constant	−3700	−695.415	−1900	1493.103	−2200	−2100
Speed of adjustment	−0.424***	−0.573***	−0.516***	−0.515***	−0.586***	−0.590***
Number of observations	141	141	141	141	141	141
Number of value chains	11	11	11	11	11	11

We report our results in Table 5. We consider three specifications separately for the whole construction sector and the construction industry. Specification (a) includes only the patent intensity as an explained variable. Specification (b) considers capital and labor contributions as additional control variables. Specification (c) decomposes the capital contribution into contributions of information technology (IT) capital and traditional production (NIT) capital. All of the models included quadratic year trends.[7] Table 5 shows estimates from 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 different value chains.

Our results showed that more intensive long-term engagement in patenting activities are 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}") varied between 0.2 and 0.6, depending on how we controlled the role of other inputs and time trends in TFP growth. The coefficient implied the effect of one more patent per 1,000 employees to the growth rate of TFP. In the case of the construction industry, we found a similar relationship, but after controlling for the direct role of inputs, this relationship became substantially weaker than in the case of the full value chain.

In our data, the number of patents per 1,000 employees was, on average, 0.47, and its standard deviation was 0.27. Thus, the analysis suggested that the average contribution of within-country patenting was somewhere between 0.1 and 0.3 percentage points for TFP productivity growth, while one standard deviation increase would be roughly one-half of the average contribution.

In addition to the role of patents, a few other interesting features arose from the data. We found that for the construction industry, the long-term relationship between capital contributions and TFP was strongly negative. This finding is most likely reflecting the influence of the financial crises and the slow return of pre-crisis construction capital investments in terms of the productivity impacts. Such an effect is not observed in the case of an increase of capital in construction value chains.

We have analyzed the role of IT capital in generating TFP growth. Our results suggested that there were major adjustment frictions in the value chains. IT capital contributions may lead to negative effects for TFP, even in the long run. It may be that productivity growth might be explained by the level of investment in IT, but problems arise due to the time lag for a new technology to reach its full potential, and those may extend beyond the length of our data set. The larger adjustment effect of ICT as compared to traditional capital seems to be a unique feature of the value chains, whereas in the case of the construction industry, the low productivity impacts of capital were common to both traditional and ICT capital.

All in all, these results suggest that productivity growth in the construction value chains is fostered by innovativeness, while the low efficiency in the use of IT may hold back their productivity potential.

[7] 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.

7. Conclusions

In this article, we discussed 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 construction industry and other sectors in the upstream value chain. We used the WIOD data, EU KLEMS data, and the method suggested by Los et al. (2016) to measure the value-add content of the value chain through the exclusion of construction activities from the WIOD.

We found that roughly half of the total value-add in the value chains generated in the value chain; a finding that is common in all observed value chains. The rest of the value-add was generated by other industries involving both manufacturing and business services. We found in particular that the role of the business services sector is important and 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 or even negative. This reallocation of productivity provides at least a partial explanation for the low productivity growth statistics in the construction sector.

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 in the adoption of IT 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 the construction and makes more visible the struggles in the adoption of technology in order to make the value chains more efficient. Together, these results suggest that future tools to improve the productivity of the sector are likely to be found from more efficient and flexible formalization of interactions in the value chain that are fostered by innovation and more efficient use of IT.

Appendix

Patent data

To measure the innovation intensity of the construction sector, we totaled the number of construction-related patent applications to the EPO by applicant country of residence and application year. We considered the following classes to be construction-related patents: B28B, B28C, B28D, C04B, E01B, E01C, E01D, E01F, E01H, E02B, E02C, E02D, E02F, E03B, E03C, E03D, E03F, E04B, E04C, E04D, E04F, E04G, E04H, E05B, E05C, E05D, E05F, E05G, E06B, E06C, E99Z, B66B, F25B, F25D, F28B, F28C, F28D, F28F, F28G, and H05B. The data were collected from the OECD Patent Statistics database.

Literature

Abbott, M., and Carson, C. (2012). A review of productivity analysis of the New Zealand construction industry. *Australasian Journal of Construction Economics and Building*, 12(3), 1–15.

Abdel-Wahab, M., and Vogl, B. (2011). Trends of productivity growth in the construction industry across Europe, US and Japan. *Construction Management and Economics*, 29(6), 635–644.

Ali-Yrkkö, J., and Kuusi, T. (2017). Shield the US from imports! GDP impacts on Finland and other European Union member states. ETLA Reports 76. https://www.etla.fi/en/publications/shield-the-us-from-imports-gdp-impacts-on-finland-and-other-european-union-member-states/

Ali-Yrkkö, J., and Kuusi, T. (2019). Brexit and indirect impact routes through global value chains. ETLA Reports 89. https://www.etla.fi/en/publications/brexit-and-indirect-impact-routes-through-global-value-chains/

Ali-Yrkkö, J., Seppälä, T., and Mattila, J. (2016). The role of the largest companies and their value chains in the economy. ETLA Reports 53. http://pub.etla.fi/ETLA-Raportit-Reports-53.

Arditi, D., and Mochtar, K. (2000). Trends in productivity improvement in the US construction industry. *Construction Management and Economics*, 18(1), 15–27.

Bankvall, L., Bygballe, L.E., Dubois, A., and Jahre, M. (2010). Interdependence in supply chains and projects in construction. *Supply Chain Management*, 15(5), 385–393.

Basu, S., and Fernald, J. (2007). Information and communications technology as a general-purpose technology: evidence from US industry data. *German Economic Review*, 8(2), 146–173.

Bresnahan, T.F., Brynjolfsson, E., and Hitt, L.M. (2002). Information technology, workplace organization, and the demand for skilled labor: Firm-level evidence. *The Quarterly Journal of Economics*, 117(1), 339–376.

Coe, D.T., Helpman, E., & Hoffmaister, A.W. (2009). International R&D spillovers and institutions. *European Economic Review*, 53(7), 723–741.

Crawford, P., and Vogl, B. (2006). Measuring productivity in the construction industry. *Building Research & Information*, 34(3), 208–219.

Davis, P., Gajendran, T., Vaughan, J., and Owi, T. (2016). Assessing construction innovation: Theoretical and practical perspectives. *Construction Economics and Building*, 16(3), 104–115.

Draca, M., Sadun, R., and Van Reenen, J. (2006). Productivity and ICT: a review of the evidence. CEP Discussion Papers, no. 749, Centre for Economic Performance, London School of Economics.

Economist (2017). The August 17th, 2017 Edition of the Economist newspaper.

Gann, D. (2000). Building innovation: Complex constructs in a changing world. London: Thomas Telford Publishing.

Grossman, G.M., and Helpman, E. (1994). Endogenous innovation in the theory of growth. *Journal of Economic Perspectives*, 8(1), 23–44.

Havenvid, M. (2015). Competition versus interaction as a way to promote innovation in the construction industry. *IMP Journal*, 9(1), pp.46–63. http://dx.doi.org/10.1108/IMP-02-2015-0005.

Houseman, S.N., and Mandel. M. (Eds.). (2015). Measuring globalization. Better trade statistics for better policy, Volumes 1 and 2. Kalamazoo, Michigan: W.E. Upjohn Institute.

Jäger, K. (2017). EU KLEMS growth and productivity accounts, 2017 release, statistical module. The Conference Board, European Commission, DG for Economic and Financial Affairs.

Jorgenson, D.W., Gollop, F.M., and Fraumeni, B. (1987). Productivity and U.S. economic growth Amsterdam: Elsevier Science Publishers.

Ketokivi, M., Turkulainen, V., Seppälä, T., Rouvinen, P., and Ali-Yrkkö, J. (2017). Why locate manufacturing in a high-cost country? A case study of 35 production location decisions. *Journal of Operations Management*, 49–51, 20–30.

Lau, E., and Rowlinson, S. (2011). The implications of trust in relationships in managing construction projects. *International Journal of Managing Projects in Business*, 4(4), 633–659.

Los, B., Timmer, M.P., and de Vries, G.J. (2016). Tracing value-added and double counting in gross exports: Comment. *American Economic Review*, 106(7), 1958–1966.

Madsen, J.B. (2008). Economic growth, TFP convergence and the world export of ideas: A century of evidence. *Scandinavian Journal of Economics*, 110(1), 145–167.

Naoum, S.G. (2016). Factors influencing labor productivity on construction sites: A state-of-the-art literature review and a survey. *International Journal of Productivity and Performance Management*, 65(3), 401–421.

O'Mahony, M., and Vecchi, M. (2005). Quantifying the impact of ICT capital on output growth: A heterogeneous dynamic panel approach. *Economica*, 72(288), 615–633.

Pesaran, M.H., Shin, Y., and Smith, R.P. (1999). Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association*, 94(44), 621–634.

Romer, P.M. (1990). Endogenous technological change. *Journal of Political Economy*, 98(5), S71–S102.

Ruddock, L., and Ruddock, S. (2011). Evaluation of trends in the UK construction industry using growth and productivity accounts. *Construction Management and Economics*, 29(12), 1229–1239.

Sezer, A.A., and Bröchner, J. (2014). The construction productivity debate and the measurement of service qualities. *Construction Management and Economics*, 32(6), 565–574.

Squicciarini, M., and Asikainen, A.-L. (2011). A value chain statistical definition of construction and the performance of the sector. *Construction Management and Economics*, 29(7), 671–693.

Stiroh, K.J. (2002a). Are ICT spillovers driving the new economy? *The Review of Income and Wealth*, 48(1), 33–57.

Stiroh, K.J. (2002b). Reassessing the impact of Information Technology in the production function: A meta-analysis. Federal Reserve Bank of New York. http://dx.doi.org/10.2139/ssrn.352820.

Sullivan, A., and Harris, F.C. (1986). Delays on large construction projects. *International Journal of Operations & Production Management*, 6(1), 25–33.

Sveikauskas, L., Rowe, S., Mildenberger, J., Price, J., and Young, A. (2016). Productivity growth in construction. *Journal of Construction Engineering and Management*, 142(10).

Timmer, M.P. (2017). Productivity measurement in global value chains. *International Productivity Monitor*, 33, 182–193.

Timmer, M.P., Los, B., Stehrer, R., and de Vries, G. (2016). An anatomy of the global trade slowdown based on the WIOD 2016 release. No. GD-162, GGDC Research Memorandum, Groningen Growth and Development Centre, University of Groningen, Netherlands.

Timmer, M.P., Dietzenbacher, E., Los, B., Stehrer, R., and de Vries, G.J. (2015). An illustrated user guide to the World Input–Output Database: The case of global automotive production. *Review of International Economics* 23(3), 575–605.

Tran, V.D., and Tookey, J.E. (2011). Labour productivity in the New Zealand construction industry: A thorough investigation. *Construction Economics and Building*, 11(1), 41–60.

Venturini, F. (2009). The long-run impact of ICT. *Empirical Economics*, 37(3), 497–515.

Vogl, B., and Abdel-Wahab, M. (2015). Measuring the construction industry's productivity performance: Critique of international productivity comparisons at industry level. *Journal of Construction Engineering and Management*, 141(4).

Winch, G. (1998). Zephyrs of creative destruction: Understanding the management of innovation in construction. *Building Research & Information*, 26(5), 268–279.

Wolff, E.N. (1994). Productivity measurement within an input–output framework. *Regional Science and Urban Economics*, 24(1), 75–92.

Zhai, D., Goodrum, P.M., Haas, C.T., and Caldas, C.H. (2009). Relationship between automation and integration of construction information systems and labor productivity. *Journal of Construction Engineering & Management*, 135(8), 746–753.

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