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Global Value Chains Participation and Knowledge Spillovers in Developed and Developing Countries: An Empirical Investigation

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Abstract In this paper we investigate the relationship between participation in global value chains (GVCs) and countries' innovation performance. We use the recently released world input–output database to build spillover variables by weighting the aggregate R&D stock of partners supplying inputs with two alternative measures of participation in GVCs: the share of foreign value added in a country's gross exports and the offshoring index. We use these indicators to test empirically the relationship between a country's innovation performance, proxied by patent per capita, and spillovers generated by GVCs. Our results show that the involvement in GVCs, in particular for developing countries importing inputs from advanced economies, is positively related with a country's innovation outcome suggesting that international fragmentation of production can indeed be a channel allowing for international technology transfer from developed to developing countries.

Nous étudions la relation entre la participation aux chaînes de valeur mondiales (CVM) et la performance de l'innovation au niveau des pays. Nous utilisons la base de données mondiale des entrées-sorties (WIOD) récemment lancée pour établir les variables de retombées en pondérant le stock total de RD des partenaires fournissant des biens avec deux autres mesures de participation aux CVM: la part de la valeur ajoutée e ´trangère dans les exportations brutes et l'indice de délocalisation. Nous utilisons ces indicateurs pour tester empiriquement la relation entre le degré d'innovation d'un pays, représenté par le nombre de brevet par habitant, et les retombées générées par les chaînes de valeur mondiales. Nos résultats montrent que l'implication dans les CVM est positivement corrélée au degré d'innovation d'un pays, en particulier pour les pays en développement importateurs des biens en provenance d'économies avancées, suggérant ainsi que la fragmentation internationale de la production peut être un vecteur permettant le transfert international de technologie des pays développés vers les pays en développement.

Keywords: global value chains; international fragmentation of production; innovation; R&D

JEL Classification: F1(4); F6(0); O3(0); O4(0)

Introduction

During the last two decades the phenomenon of international fragmentation of production (IFP) and the emergence of global value chains (GVCs) has increased both along the extensive margin, involving an increasing number of countries, industries and tasks, and along the intensive margin, showing an increase in the volumes and values traded along the GVCs.

The creation of production linkages across countries, whether through different firms or between units of the same multinational firm, can affect many economic features of a country in

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addition to international trade specialization. IFP can change the domestic organization of production not only across industries, as in traditional trade models, but also within industries, and it can be seen as a specific technological change (Feenstra and Hanson, 1996; Deardorff, 2001; Grossman and Rossi-Hansberg, 2008).

The technological change promoted by IFP affects all countries involved in this re-organization of production, albeit to a different extent. Therefore, IFP can be a vehicle of international diffusion of technological progress both through the adoption of new production techniques and through the diffusion of (tacit and codified) knowledge and ideas. Several contributions have shown that even if research and development is concentrated in a relatively small number of countries, international technology diffusion through trade and other forms of international exchanges permits technological change to be much more widespread (Keller, 2002; Keller *et al*, 2004).

Knowledge spillovers associated to trade, both through the interaction with foreign researchers and through the exchange of technology incorporated in goods, have been highlighted in the literature as an important contribution to innovation and growth since the seminal theoretical works of the endogenous growth theory, and the rich empirical stream of literature on international knowledge flows (Keller *et al*, 2004; Gong and Keller, 2003; Bottazzi and Peri, 2007; Eaton and Kortum, 1999; Coe and Helpmann, 1995; Coe *et al*, 2009; Acharya *et al*, 2009; Bloom *et al*, 2013; Malerba *et al*, 2013). The relevance of these spillovers can be enhanced when trade is generated by the IFP process, like it happens in a global production chain. GVCs are a potentially strong source of spillovers, because they encompass the full range of activities that are required to bring a good or service from conception, through the different phases of production and delivery to final users. Therefore, compared to other channels of knowledge spillovers based on traditional trade flows (Coe *et al*, 2009; Fracasso and Vittucci-Marzetti, 2015), in the case of trade driven by GVCs participation we can expect a stronger spillover (Piermartini and Rubinova, 2014; Foster-McGregor *et al*, 2016). Also in the case of developing countries, the existing evidence suggests that one of the main transmission channels through which spillovers of knowledge and technology between foreign and domestic firms may take place is supply chain linkages (Farole and Winkler, 2014).

In this paper, we focus on the relationship between international knowledge flows conveyed by GVCs and the innovation performance at the country level measured by patents. Many factors shape the nature and extent of such knowledge spillovers, and in particular the spillover potential of foreign firms within GVCs, and the absorptive capacity of local agents.[1] It is therefore meaningful to identify the sources and destinations of the spillovers and to find appropriate measures of countries' involvement in this international organization of production.

The possibility to participate in an international production process has allowed countries to enter more easily in the international market exploiting also very specific advantages through a deeper level of specialization on specific production tasks, and to enjoy in this way gains from trade. This has been very important especially for emerging and developing countries, fostering the growth of their international trade flows (UNCTAD, 2013; Kowalski *et al*, 2015; Taglioni and Winkler, 2016). Yet, in presence of such a deeper specialization, it is consequential to highlight that in principle the involvement in a GVC, together with the positive effects due to enhanced specialization and knowledge spillovers, can give rise also to negative effects, because of the reallocation of factors of production and other resources toward the "wrong" tasks from the innovation perspective. Even in the presence of positive effects of GVC participation in terms of increased trade volumes and access to better technology, because of the involvement in very specific phases of production, participation in a GVC needs not to be innovation-fostering for everyone: the incentives to innovate and patent new goods may be reduced when a country shifts resources toward production phases with low innovative content, and it still maintains access to innovative inputs through GVC participation without a domestic innovative effort. This risk might be particularly relevant for developing countries which could get stuck in low-skilled tasks.

Moreover, the relationship between GVC participation and innovation clearly depends on the stage of development of the partners involved in the GVC and how far they are from the technological frontier. The potential for knowledge transfer is larger when developing countries at intermediate stages of development are sourcing inputs from advanced economies, while the effect of the participation could be ambiguous when the relationship develops within developed or within developing partners. The potential negative relationship between GVCs participation and innovation in the short run has been observed in previous studies, especially for countries with very low absorptive capacity (Pietrobelli, 2008; Farole and Winkler, 2014). Therefore, how the participation in the GVC affects the technological frontier of a country and its innovation output in both developed and developing countries is open to empirical investigation. Aiming to test these general equilibrium effects of GVCs on resource allocation, we want to perform an aggregate, country-level analysis.

In the empirical literature, the potential effects of international knowledge spillovers are usually assessed considering as dependent variables either total/multi factor productivity (Coe and Helpmann, 1995; Keller *et al*, 2004; Coe *et al*, 2009; Fracasso and Vittucci-Marzetti, 2015; Foster-McGregor *et al*, 2016) or patents (Bottazzi and Peri, 2007; Malerba *et al*, 2013; Bloom *et al*, 2013; Piermartini and Rubinova, 2014). Following Malerba *et al* (2013), we use patent applications as a measure of innovation output. The use of direct innovation measures overcomes some of the problems related to the interpretation of productivity measures, which are made up of different components, both on the costs/inputs side and on the market/output side, an issue that can be relevant especially in the context of GVCs. Moreover, estimates of productivity at the aggregate level cannot distinguish between price (market power) and quantity (productivity) effects. Using patents presents some problems as well: patenting leaves out all those innovations which take place without being patented, depending on countries' institutions, industry characteristics, and the type of innovation, e.g., incremental innovations versus radical ones. These shortcomings might be relevant in particular when addressing the innovation performance in developing countries, where a large part of the innovation process is incremental and in many cases it might be that new processes and goods are not patented. But it is worth noting that in this perspective our findings will underestimate the potential spillover, and should therefore be seen as a lower bound. There might be international knowledge spillovers that we do not capture with our measure, inducing incremental innovation or higher efficiency/growth. We are nevertheless interested in this more narrow definition of innovation since we think that it is relevant to capture a country's perspective performance. Despite these shortcomings, patent applications can be a good, even if not exhaustive, indicator of a country's successful innovation, not (necessarily) entailing an increase in either marginal or fixed costs of production, as opposed to R&D expenditure, which represents a costly and not necessarily successful input of innovation (Malerba *et al*, 2013).

Along the lines of the previous literature on import-driven spillovers (Keller *et al*, 2004; Coe *et al*, 2009; Fracasso and Vittucci-Marzetti, 2015; Piermartini and Rubinova, 2014; Foster-McGregor *et al*, 2016), we exploit bilateral import relationships within GVCs as a source of knowledge transfer. We move a step further, as in addition to imports of intermediate goods measured through the offshoring index, we want to capture the backward participation in IFP considering the foreign value added content incorporated in goods then re-exported, by using the indicator developed by Koopman *et al* (2014) computed on the recently released world input–output database (WIOD, www.wiod.org). In principle, both the offshoring index and the GVC participation measure could work as potential channels of knowledge flows across countries, the former capturing potential spillovers coming from total imported inputs, the latter better capturing the degree of complexity in the GVC relationships. We employ these indexes to build our indicators of international knowledge spillovers, weighting the foreign R&D stock, either with the foreign value added shares or with the offshoring by partner. These indexes should capture the exposure of a country to R&D spillovers through production linkages.

Both the indexes that we consider capture downstream (or backward) GVC participation, and not upstream (or forward) participation.[2] In line with the previous contributions mentioned above weighting the R&D stock of partners with imports, looking at backward linkages is the first step to investigate international knowledge flows through GVCs. We choose to focus specifically on backward indicators rather than using a broader participation index to compare our results to ones of the cited literature on import spillovers. Furthermore, we expect that—if relevant—the potential negative effect on patenting played by imported inputs shifting resources away from domestic innovation is at work mainly through the backward channel. Certainly, forward linkages can also have a fundamental role on innovation: several contributions have shown the role of the demand side, and in particular, that of 'specialized users' (which are likely to be involved in GVC relationships) in transferring knowledge to suppliers, and in general, many studies show how buyer and supplier relationships co-evolve in generating innovation (Von Hippel, 1988 ; Malerba *et al*, 2007), but the relationship between GVC forward participation and innovation relies on quite different mechanisms that are not considered here to provide a clearer picture on one specific channel.

Another improvement with respect to the previous literature is to consider not only measures of international knowledge flows aggregated across partners, but also indicators split by group of partners and destination countries in order to address how the relationship unfolds in countries that differ in terms of development stage. We are particularly interested in the potential knowledge spillovers between developed and developing countries, therefore we focus on the interplay between developing and developed economies along the GVC by splitting into two groups both the destination and the origin countries. It is worth noting that using the WIOD database, our sample does not include the least developed countries of Africa or Asia. In the sample, developing countries are typically economies at intermediate stages of development, i.e., economies which have already overcome a 'take off' phase, and are emerging economies, potentially highly involved in GVCs, such as EU Eastern and Baltic economies, Turkey, China, India, Indonesia, Mexico, Brazil. These countries represent natural candidates for benefiting from international knowledge flows, but whether they are actually benefiting from GVCs participation is still an open question. We are also interested in investigating whether these countries are transferring knowledge within their group and/or to mature economies.[3]

We employ an empirical model of the knowledge production function in order to explore the relationship between the potential spillovers received through a country's involvement in GVCs, proxied by the indicators mentioned above, and its innovation outcome, measured by patent per capita. A positive relationship between a country's participation in GVCs and its innovation performance would suggest that IFP is a channel of international technology and knowledge transfer, fostering innovation at the country level. Instead, a negative relationship would imply that through IFP innovative activities are shifted across countries, with a potential positive effect at the world level due to greater efficiency, but with possible negative effects for some countries and positive effects for others in terms of innovation output.

Our results show that on average the involvement of a country in GVCs is positively related with a country's innovation performance when the R&D stock level of the partners is taken into account, suggesting that IFP can indeed be a channel of international knowledge spillovers. By investigating the role of the stage of development of partners involved in the GVC, we find that both developing countries and—to a slightly smaller extent—advanced economies, benefit from sourcing inputs from advanced countries. Intuitively, developing countries can receive more spillovers generated by their involvement in GVCs than economies already close to the world technology frontier. On the other hand, we find no clear evidence of knowledge spillovers from lower-income (LI) countries to the others.

The structure of the paper is as follows: "Measuring Participation in the Global Value Chains" section presents the different involvement of countries in GVC, "An Empirical Investigation on the Relationship Between Innovation and Participation in GVCs" section reports our empirical estimation of the relationship between IFP and innovation, "A Further Investigation on Innovation and GVC Participation by Country Groups" section further explores the relationship by splitting the analysis in country groups, and "Conclusion" section concludes.

Measuring Participation in the Global Value Chains

The measurement of a country's participation in GVCs is not a straightforward task, and different indicators have been proposed in the economic literature, according to the features of the phenomenon that one wants to observe. Being specifically interested in the broad impact of such participation as a channel for technological spillovers for the whole economy of a country, we chose to use two indices based on the interaction between GVC participation and the underlying production structure of a country as described by its input–output (IO) table. The advantage of using measures of participation in GVCs based on a set of inter-country IO tables is to capture the entire economic system of a group of countries, providing in this way a global picture of the occurring interactions (Timmer *et al*, 2015) that can better capture all potential spillovers. There are also some relevant open issues in measuring GVCs participation using IO tables, especially due to the relatively high level of sector aggregation (Nomaler and Verspagen, 2014). Given that our analysis is undertaken at the aggregate level in terms of overall country participation in GVCs, these shortcomings should not significantly affect our results.

Building on the previous literature based on spillovers generated by imports, as mentioned we consider two indices based on imported intermediates. The first index that we build is the so-called Feenstra and Hanson offshoring indicator (1996), developed in the early stages of the diffusion of IFP. This index is commonly used in the literature to measure the weight of imported intermediate inputs over the total use of intermediate inputs. Its main advantage is being simple and direct and it can provide a first approximation of the direct exposure of a country's production function to foreign technology embodied in imported inputs, however it is a very rough measure of participation in GVC, as it does not allow to distinguish between the simple purchase of inputs on the international market and the actual participation in a shared international production process.

For this reason we use also a more direct measure of GVC participation proposed by Koopman *et al* (2014). Using inter-country IO tables, this metric computes the share of foreign value added in a country's gross export, and it can be decomposed by country and sector of origin of the value added. This is equivalent to the vertical specialization index introduced by Hummels *et al* (2001). Even if imperfect, this index is considered a good starting point to proxy a country's involvement in the GVC, as it assesses more precisely the foreign contribution to production in terms of value added (and this difference can be very important in the case of intermediate inputs temporarily exported, processed, and re-imported again at an intermediate production stage) and by definition, looking at exports, it considers a truly international production process. One aspect that this index does not fully allow to capture is the exact role of a country in the production chain, which can be relevant in terms of spillovers.[4] Yet, the measure we adopt is defined by Koopman *et al* (2014) as backward participation index, and it can indirectly assess how downstream a country is with respect to the entire production process. We expect that on average countries involved in the final phases of the production receive a relatively higher amount of foreign value added in their production, exposing the country to a larger set of ideas and innovations, and this can be important in terms of spillovers received. In fact, regardless of the specific tasks performed by a country in the production process, GVC participation can expand the pool of knowledge available for the country proportionally to its use of imports, as suggested by Fracasso and Vittucci-Marzetti (2015).[5]

We compute the offshoring index and this FVS (foreign value added content of a country's export as a share of its export) index by using the last release of the WIOD (www.wiod.org).[6] The WIOD database is based on national accounts statistics, national IO tables, and national supply-use tables for 43 countries. The most recent release, used in this work, covers the period 2000–2014, and it provides domestic and international IO flows at the level of two-digit industries. This dataset is useful also for the aggregate analysis undertaken in this work because it was built with the specific purpose of measuring and assessing GVCs and trade in value added.[7] To compute the two indexes we adopt the same computational methodology described in Cingolani *et al* (2015).

In particular, the offshoring index is computed by summing up by sectors so that our numerator is the sum of the value of all intermediate goods imported by all intermediate goods' sectors of country i from all sectors of partners' countries s, while at the denominator we have the total value of all intermediate inputs (imported and domestically produced) used in production in all sectors of country i. The bilateral offshoring index is therefore given by the following expression:

$$\mathrm{off}^{i}_{st} = \frac{\sum_j \mathrm{import}^{i}_{jst}}{\sum_j \mathrm{input}^{i}_{jt}}, \tag{1}$$

where i is the reporting country; t is time; s is the partner from which a country imports intermediate goods; and j is a country's intermediate goods sector.

Aggregating across partners the aggregate index is given by:

$$\mathrm{off}_{it} = \sum_s \mathrm{off}^{i}_{st}, \tag{2}$$

where t is time; i is the reporting country; and s is the partner from which a country imports intermediate goods.

As for the second index, we derive the bilateral measures of domestic and foreign shares of value added incorporated in country i gross exports following Koopman *et al* (2014),

$$\mathrm{dvs}^{i}_{t} = \mathrm{DV}_{it}/E_{it} \tag{3}$$

and

$$\mathrm{fvs}_{st}^{i} = \mathrm{FV}_{st}^{i}/E_{it}, \tag{4}$$

where t is time; i is the reporting country; s is the partner; DV_t^i is the value added generated by country i included in its own export; FV_{st}^i is the value added generated by partner s included in country i export; and E_{it} is total export of country i.

From the bilateral measures fvs_{st}^i of the foreign value added content of a country export as a share of its export, aggregating across partners we obtain an aggregate measure of the foreign value added share of a country total export:

$$\mathrm{fvs}_{it} = \sum_{s} \mathrm{fvs}_{st}^{i}. \tag{5}$$

The two indexes on GVC participation are presented in Table 1, where countries are sorted in terms of their FVS indicator in 2014, with countries most involved in GVCs at the top.[8]

As shown in Table 1, both the FVS and offshoring indexes present relevant variations across countries. On average, in 2014 the value of the FVS index is 0.31, implying that the average share of foreign value in export in the countries of our sample is about one-third. This share is higher than the weight of imported inputs measured through the offshoring index, whose average in 2014 is 0.28. Generally, as expected smaller countries tend to be at the top of the table, receiving a higher share of foreign value added, as their exports rely heavily on imported inputs. But not all small countries are participating in GVCs to the same extent, and therefore we find some small countries also in the middle of the list. Also, looking at the ranking of GVC participation in Table 1, there is no obvious pattern linking this measure to higher or lower GDP per capita in our sample. In fact, GVC participation can be driven by very different factors, ranging from the search of lower production costs to the need to find the best and more advanced inputs in complex production. Over our observation period, the average value of the FVS increased by five percentage points, as most countries in the sample experienced a growing involvement in GVC. The increase has not been uniform: some emerging countries, such as China, experienced a period of rapid increase until the onset of the international financial crisis of 2007–2008, and then a partial reduction. In general, after the international financial crisis, some GVCs have shortened because of the difficult phase of the business cycle. Also, in the last years, some emerging countries, proceeding in their development process, tried to expand the scope of their domestic production, reducing somewhat GVC participation (Hanson, 2012). Emerging countries whose exports are heavily based on energy and raw materials, such as Russia and partially Brazil, tend to display very low FVS values. Instead, most Central and Eastern European countries appear fully integrated in the European production processes and they have relatively high indexes of GVC participation. This variety in the degree of participation might also hint to a variety of roles and positions in the existing GVCs, and therefore it leads to the question of the impact of such participation on the economic performance of countries, as also pointed out by Lee *et al* (2017).

An Empirical Investigation on the Relationship Between Innovation and Participation in GVCs

To test how participation in GVCs is related to the innovation outcome of countries, we analyze the empirical relationship between some specifically built international spillover measures and

Table 1: Measures of participation in global value chains

Countries	*Foreign value added 2014*	*Foreign value added 2000*	*Offshoring index 2014*	*Offshoring index 2000*
Luxemburg	0.6594	0.5527	0.5887	0.5788
Malta	0.6526	0.575	0.5885	0.5466
Hungary	0.5170	0.4766	0.5138	0.3894
Ireland	0.4914	0.4062	0.6034	0.4231
Slovakia	0.4793	0.3822	0.4047	0.2429
Czech	0.4564	0.3132	0.3564	0.2367
Belgium	0.4561	0.3719	0.4237	0.3277
Estonia	0.4335	0.3545	0.3970	0.2869
Taiwan	0.4142	0.3749	0.3355	0.3003
Bulgaria	0.3815	0.3118	0.3273	0.2304
Denmark	0.3734	0.3104	0.3493	0.2925
Slovenia	0.3724	0.3293	0.3492	0.2639
Netherlands	0.3603	0.2550	0.3676	0.2611
Austria	0.3583	0.2844	0.3142	0.2644
Lithuania	0.3565	0.2303	0.4420	0.2470
Finland	0.3487	0.2590	0.2589	0.1997
Korea	0.3479	0.2977	0.218	0.1931
Mexico	0.3329	0.3244	0.2838	0.2561
Portugal	0.3106	0.2778	0.2568	0.2084
Latvia	0.3090	0.2387	0.2544	0.2089
Spain	0.3085	0.2553	0.1968	0.2061
Poland	0.3069	0.2456	0.2542	0.2017
Greece	0.3036	0.1896	0.2494	0.1912
Sweden	0.2850	0.2799	0.2549	0.2459
Turkey	0.2840	0.1615	0.2132	0.1281
Cyprus	0.2799	0.3247	0.3155	0.2911
France	0.2724	0.2373	0.2104	0.1790
Croatia	0.2724	0.2434	0.3033	0.2781
Germany	0.2674	0.2202	0.2399	0.1807
Romania	0.2662	0.2498	0.2460	0.2247
Italy	0.2604	0.1904	0.1661	0.1404
Switzerland	0.2531	0.2293	0.2305	0.2111
Canada	0.2380	0.2808	0.2166	0.2287
Japan	0.2326	0.0934	0.1469	0.0629
India	0.2061	0.1313	0.1612	0.1215
UK	0.1895	0.1755	0.1787	0.1616
Indonesia	0.1714	0.1832	0.1816	0.2108
Norway	0.1678	0.1313	0.2197	0.1897
China	0.1591	0.1641	0.0644	0.0779
Australia	0.1402	0.1502	0.1211	0.1150
Brazil	0.1278	0.1162	0.1181	0.0917
USA	0.1214	0.0976	0.1026	0.0790
Russia	0.0750	0.0934	0.0945	0.1260
Rest of the World	0.2479	0.2617	0.2047	0.2515

Notes: the foreign value added in a country's export is computed as in Koopman *et al* (2014) for each year and the offshoring index is the ratio between the value of imported intermediate inputs and the value of all intermediate inputs. Countries are ordered in terms of the FVS index in 2014.
Source: our elaborations on the WIOD database.

patent per capita, controlling for other determinants of a country's innovation performance and a number of countries' characteristics.

Spillover Variables

We follow the existing literature on international knowledge spillovers to build our spillover variables. In particular, we start from the contributions showing that trade is a relevant channel of international knowledge spillovers (Coe and Helpmann, 1995; Coe *et al*, 2009; Fracasso and Vittucci-Marzetti, 2015), and we compute our spillover variables by weighting the aggregate R&D stock of partners with the two alternative measures of participation in GVCs mentioned in the previous section: the offshoring index by partner (off^i_{st}), as in Equation (1), and the foreign value added content of a country's export imported from each partner (s) by the reporting country (i) as a share of its export, (fvs^i_{st}) as in Equation (4). Our measures also capture the openness of the country with respect to imported inputs. Two countries with the same trade partners' structure should be differently affected by the partners' R&D stock also depending on the volume they import (aggregated across partners) relative to what they produce domestically (Coe and Helpmann, 1995; Lichtenberg and van Pottelsberghe de la Potterie, 1998; Coe *et al*, 2009; Foster-McGregor *et al*, 2016). With respect to Foster-McGregor *et al* (2016) and Piermartini and Rubinova (2014) who build measures of GVC participation in terms of import of intermediate inputs, we also add the relative value added measure of participation in the GVC, i.e., the fvs^i_{st}.

Our measures of spillovers are therefore:

$$\text{OFFRD}_{it} = \sum_s \text{off}^i_{st} * \text{R\&D}_{st} \tag{6}$$

and

$$\text{FVSRD}_{it} = \sum_s \text{fvs}^i_{st} * \text{R\&D}_{st}, \tag{7}$$

where i is the reporting country; t is time; s is the partner from which a country imports intermediate goods; off^i_{st} and fvs^i_{st} are the share of inputs as in Equation (1) and the foreign value added share as in Equation (4), respectively, imported from partner s by country i; and $\text{R\&D}_{st}$ is the stock of R&D of partner s at time t.[9]

The Empirical Framework

To assess the role of international knowledge spillovers through GVCs, we borrow from the knowledge production function approach (Malerba *et al*, 2013; Coe and Helpmann, 1995; Coe *et al*, 2009) by considering the R&D stock accumulated at time t as the main determinant of a country's patent applications at time t, and therefore we include it in all the specifications. We consider the following equation:

$$\text{PAT}_{it} = a_0 + a_1\text{RDstock}_{it} + a_2\text{GVCRD}_{it} + a_3X_{it} + u_t + u_i + \epsilon_{it}, \tag{8}$$

where the dependent variable is country i's patent applications per capita at time t, and RDstock_{it} is country i's R&D stock at time t, which are standard measures of innovation output and input, respectively.[10] GVCRD_{it} are our measures of spillovers mediated by participation to the GVC [either OFFRD as in Equation 6 or FVSRD as in Equation 7]; X_{it} is a vector of other control variables; u_t and u_i are time and country fixed effects, respectively; and ϵ_{it} an error term.[11] In all our specifications both the dependent variable and the explanatory variables are in logarithm, and therefore the estimated coefficients can be interpreted as elasticities.[12] In Table 2 we show the estimates of the model in Equation (8). The first four columns refer to the FVSRD indicator, while the last four columns refer to the OFFRD indicator.

As a first step, in our baseline specification, we investigate the relationship between a country's innovation outcome proxied by patent and participation in the GVC by considering, separately, both our indicators of knowledge spillovers, and including only the country's R&D stock as the main innovation input commonly considered in the literature. It is worth noting that the R&D stock measures also the closeness to the world's technological frontier. In Columns 1 and 5 of Table 2, we show results controlling for a country's own R&D stock.

As a second step, we include a group of control variables to bring in additional potential determinants of innovation performance at the country level other than investment in R&D to check the robustness of our estimates. We include GDP per capita, to control for the level of development of a country (Piermartini and Rubinova, 2014): this should capture the resources available for innovation activities, and at the same time, it conveys information on the sectoral composition in terms of the main macro sectors. We also include a proxy of the level of human capital (HC) of a country (Piermartini and Rubinova, 2014), using the HC index computed in the Penn World Tables (Feenstra *et al*, 2015): this variable should affect both the innovation and absorptive capacity of a country. We also measure the country's size in terms of population, given that economic size is well known to strongly affect the propensity to trade across borders. This first group of controls is included in Columns 2 and 6 of Table 2.

As a third step, we include a group of variables controlling for channels, other than participating in GVCs, which could also lead to international spillovers. We consider an alternative measure of international knowledge spillover by weighting the R&D of partners with imports of final goods (FINRD).[13] We then include foreign direct investments (FDI net inflows, per cent of GDP) and a measure of a country's openness computed as the sum of total import plus total export on valued added. As mentioned, we build our variables of spillovers in order to take into account that larger trade flows should vehicle larger knowledge flows; but we want to control that our spillover measures are not simply capturing openness and therefore other channels of knowledge exposure. In Columns 3 and 7 of Table 2, we add this second set of controls.

Last, we include two more variables to control for geographical distance (or a country's geographic centrality) and the relevance of trade with third countries not included in the analysis. We build a measure of international knowledge spillover by weighting the R&D of partners with the inverse of geographical distance (DISTRD)[14] to control for spillovers that might arise because of geographical proximity (or common borders) between countries (Keller *et al*, 2004; Piermartini and Rubinova, 2014; Bottazzi and Peri, 2007). On the basis of arguments belonging to the economic geography literature, spillovers can occur because countries are located close to each other, regardless of whether there is any GVC connection. Finally, we added to the regressions the offshoring index and the foreign value added measure from the Rest of the World,[15] that is the residual group of countries not individually covered in the WIOD database for which the spillover indexes could not be computed. This aims at controlling for additional GVC connections that cannot be explicitly accounted for by our analysis.[16] In Columns 4 and 8 of Table 2, we add the DISTRD indicator and the GVC trade with the residual group of countries.

All variables' definition and sources are listed in Table 11 in "Appendix", while Table 9 provides the sample descriptive statistics and Table 10 the cross-correlations among them.

Dataset

As mentioned in "Measuring Participation in the Global Value Chains" section, we rely on the recently released update version of the WIOD dataset in building the two indexes of IFP. We use WIOD data for building all the spillover variables, the openness measure, and the variable controlling for exchanges with the Rest of the World. We use OECD data on patents applications to the European Patent Office (EPO) (OECD, 2017) for the dependent variable, by inventors' country of residence and priority date, i.e., the first filing worldwide and therefore closest to the invention date.[17] Counting patents according to the inventors country of residence is the most relevant way for measuring the technological innovativeness of researchers and laboratories located in a given country (OECD, 2009). Moreover, by using patent by residence of the inventor, we are capturing where the new process or good is invented: therefore we exclude those patenting of multinational firms (MNEs) in foreign markets where all the knowledge is kept within the MNEs borders.[18] We use the World Development Indicators database from the WB for data on GDP and R&D expenditure,[19] from which we built the R&D stock, on population stock, and FDI net inflows (per cent of GDP), while we rely on the Penn World Tables version 9.0 (Feenstra *et al*, 2015) for the HC index.[20] Distance weights are taken from CEPII GeoDist database (Mayer *et al*, 2011). In our whole sample we have 15 years (2000–2014) and 42 countries.

Results

Results are reported in Table 2. In line with previous contributions, the R&D stock and the GDP per capita are always positively and significantly associated with patents in all models, with highly significant coefficients, in particular for the R&D stock. The inclusion of the GDP per capita reduces considerably the magnitude of the R&D stock coefficient. Conditional on R&D, the HC endowment shows a positive relation with patent per capita, with a high, but very imprecisely estimated, coefficient.

The spillover variables mediated by GVC participation, FVSRD and OFFRD, are both significantly and positively related to patents, the magnitude of the coefficient decreasing with the inclusion of the first group of controls, while increasing in the last two specifications when other foreign sources of knowledge are included. The elasticity is around 0.8 for FVSRD and 1 for OFFRD in our preferred specification where all controls are included, i.e., Columns 4 and 8, respectively.[21]

It is worth noting that since we control for a country's own R&D stock, the coefficient of GVC indicators should not be capturing an incentive channel of investing in R&D due to resource relocation. We are therefore capturing an effect which goes over and above what affects investments in R&D (i.e., a spillover). By including the second set of controls, i.e., FINRD, inward FDI, and openness, we can say that the positive relationship captured by the GVC spillover variable is not due to other sources of foreign spillovers. Finally, by controlling for GVC relationships with residual countries and with DISTRD, we can exclude that our coefficients are capturing exchanges of knowledge with countries excluded from our analysis or pure geographical proximity.

Table 2: Models of international knowledge spillovers through global value chain (GVC) participation

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
R&D stock	1.162***	0.693***	0.737***	0.816***	1.155***	0.713***	0.757***	0.843***
	(0.267)	(0.250)	(0.211)	(0.202)	(0.254)	(0.221)	(0.195)	(0.213)
GDP per capita		1.371***	1.448***	1.540***		1.287***	1.380***	1.452***
		(0.376)	(0.334)	(0.295)		(0.369)	(0.331)	(0.298)
Human capital		1.325	1.244 (1.694)	1.184 (1.655)		1.229	0.972	0.879
		(1.607)				(1.653)	(1.840)	(1.718)
FVSRD	0.709***	0.585***	0.913***	0.815***				
	(0.231)	(0.206)	(0.299)	(0.267)				
OFFRD					0.808***	0.638**	1.021***	1.008***
					(0.285)	(0.266)	(0.315)	(0.287)
Additional controls								
Population	No	Yes	Yes	Yes	No	Yes	Yes	Yes
FINRD	No	No	Yes	Yes	No	No	Yes	Yes
Inward FDI	No	No	Yes	Yes	No	No	Yes	Yes
Openness	No	No	Yes	Yes	No	No	Yes	Yes
DISTRD	No	No	No	Yes	No	No	No	Yes
FVS/OFF from residual group	No	No	No	Yes	No	No	No	Yes
R^2(a)	0.2801	0.4379	0.4592	0.4720	0.3095	0.4527	0.4839	0.4963
N	510	510	510	510	510	510	510	510

Note: dependent variable: patent per capita. All models include year and country FE. All variables are in logarithm and lagged 1 year. Standard errors are clustered at the country level. FVSRD is the stock of R&D of trade partners weighted by the foreign value added flows imported by partner on total export as in Equation (7). OFFRD is the stock of R&D of trade partners weighted by the offshoring index by partner as in Equation (6).
$^{*}p< 0.10$, $^{**}p< 0.05$, $^{***}p< 0.01$
(a)Within R^2.

Robustness Checks

By construction, our spillover variables combine the effect of varying the composition of trade partners over time with the time-varying R&D stock of partners. This means that with these variables it is not possible to disentangle the role of the variation in the stock of R&D of the partners from the role of the variation in the GVC participation measured by the value of offshoring/FVS by partner. This is common to other contributions in the international knowledge spillover literature weighting trade partners' R&D with trade variables (Coe and Helpmann, 1995; Coe *et al*, 2009).

To single out the two channels we estimated the model in Equation (8) by keeping constant at the initial year (i.e., 2000), first, the foreign value added by partner and the offshoring by partner (see Table 6 in "Appendix"), and then, the R&D stock of the partners (see Table 7 in "Appendix").[22]

Our results show that when we fix at the initial year the GVC participation variables, the spillover variables are not statistically significant anymore, while the opposite occurs when we fix the R&D stock at the initial year. This is most likely due to the very low variation in the R&D stock of the partners in the relatively short period considered.[23] This check allows us to conclude that our results are mainly driven by the variation in GVC variables and that the estimated effect stems from the variation of both the intensive and the extensive margins of participation in the GVC in the period considered.[24]

We do not exclude that countries might intentionally choose the portfolio of partners from which they source their inputs. For instance, they could choose partners with higher R&D stocks. Our results show that these countries would in this case take advantage of their choice by benefiting of higher spillovers. This is actually a possible policy implication of our work: countries might benefit from choosing higher R&D partners. A potential source of endogeneity nevertheless could arise should either positive or negative selection take place on the destination countries' R&D stock (the GVC weights being correlated with the error term in our equation). We address this potential source of endogeneity (self-selection on technological level) by controlling in the regressions for the destination country's R&D stock (time variant) and including country fixed effects (which, for instance, control for the stock of patent at time zero of the destination country). As a further check for self-selection, we also estimated bilateral offshoring and foreign value added flows through a gravity model where we include both the R&D stock of the origin country (from where inputs/foreign value are imported) and that of the destination country.[25] We show that the GVC flows are correlated with the R&D stock of the origin country, that is to say that the partners' attractiveness in term of R&D intensity, not surprisingly, matters, but it is not related with the R&D stock of the destination country (see Table 8 in "Appendix") excluding therefore selection on this variable. The fact that the GVC weights depend on the partners' stock of R&D means that the R&D stock is a pull factor in driving the decision to internationalize production, as it is well known by previous literature.

A Further Investigation on Innovation and GVC Participation by Country Groups

Splitting Advanced and Developing Countries

As mentioned above, the extent of spillovers related to GVC participation depends crucially on many characteristics of the countries involved (see for example Pietrobelli, 2008; Farole and

Winkler, 2014). Therefore, we estimate a modified version of our baseline model that allows to distinguish among country groups to further investigate whether the relationship between participation in GVCs and innovation changes according to the different stages of development of countries. We build two groups of countries according to the World Bank (WB) classification.[26]

We expect the positive relationship between GVC participation and innovation to be larger for countries at an earlier stage of development, i.e., with a lower-income per capita. This is because countries with lower GDP per capita should have larger room for improvement, according to the literature on the knowledge frontier and catching up. It is worth noting that our sample does not include least developed economies (e.g., African countries are not included). Therefore, lower-income countries in our sample are transition economies which already completed a 'take off' stage and which are potentially highly involved in GVCs.

We build a dummy variable, higher/lower-income countries (HI/LI) according to WB classification, and interact the spillover variables with these country groups to estimate the following specifications:

$$\mathrm{PAT}_{it} = a_0 + a_1 \mathrm{RDstock}_{it} + a_2 \mathrm{GVCRD}_{it} + a_3 \mathrm{GVCRD}_{it} * \mathrm{HI} + a_4 X_{it} + u_t + u_i + \epsilon_{it}, \quad (9)$$

where GVCRD_{it} is either OFFRD_{it} as in Equation 6 or FVSRD_{it} as in Equation 7 and the excluded group is the LI group.

We estimate the model by including all control variables as in our preferred specifications in Columns 4 and 8 in Table 2.

As a further split, we investigate the role of different types of partners by splitting the source of spillovers into two groups according to the WB classification. We build four new spillover variables for the two groups of partners, i.e., the origin countries, and the two GVC channels: FVSRDHI partners, FVSRDLI partners, OFFRDHI partners, OFFRDLI partners. We look at the average relationship between innovation and exchange of knowledge through GVC participation with higher-income partners and lower-income partners. According to previous contributions (Coe *et al*, 1997, 2009; Keller *et al*, 2004; Comin *et al*, 2013), we expect that the potential positive relationship between innovation and GVC participation through knowledge exchange should be larger when the origin partners are higher-income countries, i.e., technologically advanced and more innovative countries.

In the last step, we make an attempt to consider simultaneously both the countries' heterogeneity dimensions mentioned above, destination and origin, by building an interaction between the four new variables where the channel of spillover is split by type of partners and type of destination country (higher-income and lower-income countries). Here we investigate simultaneously the interplay between the level of development of the origin country and that of the destination country.

$$\begin{aligned} \mathrm{PAT}_{it} = {} & a_0 + a_1 \mathrm{RDstock}_{it} + a_2 \mathrm{GVCRDHI}_{it} + a_3 \mathrm{GVCRDHI}_{it} * \mathrm{HI} + a_4 \mathrm{GVCRDLI}_{it} \\ & + a_5 \mathrm{GVCRDLI}_{it} * \mathrm{HI} + a_6 X_{it} + u_t + u_i + \epsilon_{it}, \end{aligned} \quad (10)$$

where GVCRD_{it} is either OFFRD_{it} as in Equation 6 or FVSRD_{it} as in Equation 7, and the excluded group is the LI group.

Sub-samples Results

In Table 3 we show estimates of the model (9), for the FVSRD spillover variable and the OFFRD spillover variable (Columns 1 and 2, respectively). Both spillover variables are

Table 3: Knowledge spillovers through GVC in advanced and developing countries

	(1)	*(2)*
R&D stock	0.801***	0.841***
	(0.198)	(0.210)
GDP per capita	1.460***	1.410***
	(0.313)	(0.317)
Human capital	0.950	0.643
	(1.658)	(1.781)
FVSRD	1.125***	
	(0.413)	
FVSRD × HI	−0.424	
	(0.367)	
OFFRD		1.159**
		(0.432)
OFFRD × HI		−0.189
		(0.371)
FVSRD + FVSRD × HI	0.7011***	
	(0.2456)	
OFFRD + OFFRD × HI		0.9698***
		(0.2839)
R^2(a)	0.4782	0.4979
N	510	510

Note: dependent variable: patent per capita. All models include year and country FE. All variables are in logarithm and lagged 1 year. Standard errors are clustered at the country level. FVSRD is the stock of R&D of trade partners weighted by the foreign value added flows imported by partner on total export as in Equation (7). OFFRD is the stock of R&D of trade partners weighted by the offshoring index by partner as in Equation (6). All models include all control variables as in Models 4 and 8 in Table 2, for the FVSRD spillover and the OFFRD spillover, respectively, our preferred specifications.
$^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$
(a)Within R^2.

positively and significantly related with the invention performance in all the sub-samples. The size of the coefficient is nevertheless larger in the lower-income group of countries than in the higher-income group (see the coefficients in the last two lines in Table 3). This is in line with what we expected and what was found by previous contributions (Amighini, 2005; Ivarsson *et al*, 2010): given that we are excluding least developed economies, countries at an earlier stage of development in our sample benefit more strongly from international knowledge spillovers than advanced economies.

In general we can claim that participation in the GVC seems to be a relevant channel of knowledge transmission, both when measured in gross terms and in value added terms for both advanced and developing countries, with the latter benefiting more that the former.

In our last tables, we try to address the interplay between the different levels of development of countries, both of origin and of destination.

In Table 4 we report the estimates of model (8), but here the spillover variables are built by splitting origin countries according to their income level. For both indicators, the knowledge spillover variable is positively and significantly associated with the innovation performance when related to trading with higher-income suppliers (Columns 1 and 2 for FVSRD and OFFRD, respectively). The elasticity is in between 0.8 and 1. When the origin country in the GVC belongs to a lower-income group, we find instead no significant relationship between the GVCs participation and patenting. Moving to developing countries, the low value added stages

Table 4: Knowledge spillovers from advanced and developing partners in GVC

	(1)	*(2)*
R&D stock	0.807***	0.833***
	(0.205)	(0.211)
GDP per capita	1.588***	1.471***
	(0.311)	(0.272)
Human capital	1.157	0.648
	(1.507)	(1.593)
FVSRD from HI partners	0.826***	
	(0.218)	
FVSRD from LI partners	0.101	
	(0.104)	
OFFRD from HI partners		0.999***
		(0.245)
OFFRD from LI partners		0.042
		(0.067)
R^2(a)	0.4760	0.5061
N	510	510

Note: dependent variable: patent per capita. All models include year and country FE. All variables are in logarithm and lagged 1 year. Standard errors are clustered at the country level. FVSRD is the stock of R&D of trade partners weighted by the foreign value added flows imported by partner on total export as in Equation (7). OFFRD is the stock of R&D of trade partners weighted by the offshoring index by partner as in Equation (6). All models include all control variables as in Models 4 and 8 in Table 2, for the FVSRD spillover and the OFFRD spillover, respectively, our preferred specifications.
$*p < 0.10$, $**p < 0.05$, $***p < 0.01$
(a)Within R^2.

of the GVC might be a source of cost reduction which might free resources for investing in R&D, but, conditional on R&D, does not represent a source of knowledge spillover itself.

In the last regressions, we make an attempt to further investigate this latter insight, by disentangling the role of different origin countries from that of different destination countries. In Table 5 we report the estimates of model (10). Columns 1 and 2 report results for the FVSRD and the OFFRD variable, respectively. Here we show that developing countries benefit strongly by being involved in a GVC with advanced partners. This emerges in all the specifications, both when the spillover relates to the foreign value added measure and to the gross measure of offshoring. The size of the coefficient is quite large (1.2 and 1.1, for the FVSRD and the OFFRD variable, respectively).

Advanced countries also benefit from a knowledge spillover from other higher-income partners, but to a lesser extent. With respect to lower-income countries, the coefficient decreases by about 0.43 and 0.18 per cent for the FVSRD and the OFFRD spillover, respectively (Columns 1 and 2). This is reasonable since advanced countries are closer to the technological frontier and do most of the world innovation (Keller *et al*, 2004): the room left for a spillover effect is limited and it could work through exchanges other than GVC participation.

Turning the attention to the role of lower-income countries as origin of spillovers, a different picture emerges. The relationship between innovation and the spillover variable from lower-income origin partners is never significant, neither for developing nor for developed destination countries, regardless of the type of indicator (based on foreign value added, FVSRDLI, or based on offshoring, OFFRDLI) considered. This is not surprising, because lower-income origin countries, being generally further away from the technological frontier can generate smaller spillovers. Moreover, lower-income destination countries participating in GVCs with other

Table 5: Knowledge spillovers in GVC between advanced and developing partners

	(1)	*(2)*
FVSRD from HI partners (a)	1.271***	
	(0.339)	
FVSRD from HI partners × HI (b)	−0.557*	
	(0.308)	
FVSRD from LI partners (c)	0.160	
	(0.114)	
FVSRD from LI partners × HI (d)	−0.083	
	(0.083)	
OFFRD from HI partners (e)		1.172***
		(0.333)
OFFRD from HI partners × HI (f)		−0.217
		(0.338)
OFFRD from LI partners (g)		0.061
		(0.094)
OFFRD from LI partners × HI (h)		−0.036
		(0.081)
FVSRD from HI partners in HI (a + b)	0.713***	
	(0.211)	
FVSRD from LI partners in HI (c + d)	0.076	
	(0.096)	
OFFRD from HI partners in HI (e + f)		0.954***
		(0.260)
OFFRD from LI partners in HI (g + h)		0.024
		(0.064)
R^2(a)	0.4894	0.5091
N	510	510

Note: dependent variable: patent per capita. All models include year and country FE. All variables are in logarithm and lagged 1 year. Standard errors are clustered at the country level. FVSRD is the stock of R&D of trade partners weighted by the foreign value added flows imported by partner on total export as in Equation (7). OFFRD is the stock of R&D of trade partners weighted by the offshoring index by partner as in Equation (6). All models include all control variables as in Models 4 and 8 in Table 2, for the FVSRD spillover and the OFFRD spillover, respectively, our preferred specifications.
$*p < 0.10$, $**p < 0.05$, $***p < 0.01$
(a)Within R^2.

lower-income origin countries can get involved in low-skilled tasks and low-tech production stages with no room for innovation or improvement (Pula and Peltonen, 2011). For advanced countries, given the relative technological levels, the possibility of spillovers from sourcing from developing countries is generally limited. Also, in advanced countries sourcing from developing countries, the incentive to innovate can be lowered if outsourcing from lower-income countries is a strategy to control costs in the production process of mature products allowing for a longer product life.

Conclusion

In this paper, we investigate whether participation in GVCs can be a vehicle of international knowledge spillovers, therefore affecting a country's innovation outcome, measured by patent per capita. We move from the existing literature on international knowledge spillovers to build our spillover variables, by weighting the aggregate R&D stock of partners supplying inputs with two alternative measures of participation in GVCs: the foreign value added flows imported from each partner by the reporting country as a share of export and the offshoring index.

In our sample of countries, we find evidence of a positive spillover from sourcing inputs along a GVC. In particular, our results show that both developing and advanced economies benefit in terms of increased patenting from sourcing inputs from high-income countries. The positive effect on patents of developing countries is expected when knowledge spillovers are present, but it is not the only conceivable outcome. In principle, it is possible that GVC participation could push developing countries to specialize in tasks with low innovative content, reducing the amount of resources employed to expand the technological frontier. And the positive spillovers also depend on the specific partners involved in the GVC: in our sample, neither developing nor advanced countries benefit from sourcing inputs from lower-income countries.

These findings on the presence of international knowledge spillovers in GVCs, in particular for developing countries sourcing inputs from advanced ones, have a number of possible policy implications. First of all, participation of developing countries' firms in GVCs originated in advanced countries can be encouraged and facilitated in some conditions. This can be done, for example, through international trade agreements reducing barriers to the circulation of intermediate inputs among countries (Miroudot *et al*, 2013; OECD, 2015). Given that the potential benefits depend crucially on the specific economic environment of the participating countries, confirming the observation by Kowalski *et al* (2015), in developing countries improving institutions directly involved in the business environment (patent protection, contract enforcement, bureaucracy) is relevant also to maximize the benefits from GVC participation, in order to ease the appropriate matching between buyers and suppliers located in different countries.

Moreover, to enhance the impact of GVC spillovers, national and local policies aiming at improving the absorptive capacity of developing countries are very important (Taglioni and Winkler, 2016), as well as policies, possibly at the industry level, aiming at reducing technical incompatibilities between production processes in developing and developed countries and improving production flexibility of firms in developing countries. Such policies need not target high-tech industries only. Innovation through knowledge spillovers can occur also in traditional sectors—such as textiles or agriculture—thanks to the use of new production techniques adopted by participating in GVCs in those sectors, and it can diffuse to other industries of the economy through domestic value chains that receive inputs produced with new technologies. Finally, also in advanced countries, R&D policies should take into account the positive externality generated in developing economies through GVC participation.

These results provide a first set of useful indications, but they also call for further investigation to better understand the complex relationships between innovation and GVCs participation and therefore they are the natural starting point for our future work.

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Notes

1. In addition, the specific dynamics of GVCs for mediating spillovers are quite important: the sectors involved, the strategies of lead firms governing GVCs, the global production, and sourcing policies of firms all affect the extent of spillovers (Gereffi *et al*, 2005; Gereffi *et al*, 2010; Pietrobelli and Rabellotti, 2011). In this work, aiming to capture the broad effect of GVCs in terms of knowledge spillovers, we consider only some of these aspects.
2. On the interpretation of the backward and forward participation indices to measure GVC participation, see Taglioni and Winkler (2016, especially Chaps. 3 and 4).
3. Using patents as an indicator of innovation means that having in the sample advanced economies and emerging countries at an intermediate stage of development allows to include over 90 per cent of the patents filed worldwide (see WIPO 2016).
4. The relevance of the upstream or downstream position of a country in the GVC is discussed in Antras *et al* (2012).
5. This is also the reason why we do not remove double-counting of trade flows in our indicator, as suggested by Koopman *et al* (2014) for other studies, where it is important to isolate net trade flows to measure their impact. Given that what matters here is the overall exposition and use of inputs produced abroad, double-counting is not a matter of concern, as repeated use can increase the exposure to spillovers.
6. Alternative databases with multi-country IO tables that can be used to compute indices of GVC participation are the TiVA database, provided by WTO–OECD and the EORA database. We chose to use WIOD instead of EORA because the dataset was built specifically to study IFP, and its geographic coverage includes all the most relevant countries in terms of patenting; with respect to TiVA it allows for a longer time span.
7. For a detailed description of the dataset, see Stehrer (2012) and Timmer *et al* (2015).
8. Even if measuring more precisely GVCs participation, the FVS index is highly correlated with the offshoring index (correlation coefficient 0.9275).
9. We follow the literature in constructing the domestic R&D stock using the perpetual inventory method and allowing for depreciation $\text{RDstock}_{it} = (1-\delta)\text{RDstock}_{it-1} + \text{RDexp}_{it}$ where $\text{RDstock}_{it0} = \frac{\text{RDexp}_{it0}}{\delta+g}$ and where the depreciation rate is assumed to be 0.15 and g is the annual average logarithmic growth rate $g = \frac{1}{T-t0} * \log \frac{\text{RDexp}_{iT}}{\text{RDexp}_{it0}}$. As reported in Coe *et al* (2009) empirical results are not sensitive to the depreciation rate; we nevertheless did robustness checks by using also $\delta = 0.10$ as in Foster-McGregor *et al* (2016) and results do not change.
10. See Bottazzi and Peri (2003, 2007).
11. By introducing country fixed effects we are exploiting within-country variation over time. This strategy allows us to address some of the endogeneity concerns which may emerge in our framework, namely those produced by time-unvarying components which are country specific.
12. We cluster standard errors at the country level to account for serial autocorrelation. We did robustness check to fully control for arbitrary autocorrelation and cross-sectional dependence, by two way clustering, performing cluster wild bootstrap for the baseline analysis of Table 2. Since Pesaran test of cross-sectional dependence in Panel data does not reject the null hypothesis of cross-sectional independence, we present results relying on clustering at the country level only. Results of the robustness check are available upon request.
13. We compute the final import weighted spillover index as $\text{FINAL}^{i}_{st} = \frac{\sum_j \text{impfinal}^{i}_{jst}}{\sum_j \text{final}^{i}_{jt}}$, where i is the reporting country; t is time; s is the partner from which a country imports final goods; and j is the sector. Aggregating across partners we obtain an index of foreign spillover where partners' R&D is weighted by final goods imports: $\text{FINRD}_{it} = \sum_s \text{FINAL}^{i}_{st} * \text{R\&D}_{st}$. We also did our analysis by weighting the R&D of partners with total import. Results do not change. We prefer to report results by using final import share since our measures of GVC spillover are highly correlated with total import (the coefficient of correlation is about 0.9) due to the fact that total import clearly includes import in intermediate goods.
14. The distance weighted spillover index is computed as $\text{DISTRD}_{it} = \sum_s \frac{\text{R\&D}_{st}}{\text{DIST}^{i}_{st}}$ where i is the reporting country; t is time; s is non-i countries included in WIOD.

15. The Rest of the World is a residual category in WIOD tables, for which we could not compute the R&D stock; we add to this residual group also Taiwan, which is not included in World Bank (WB) data and for which we would have therefore missed information on R&D expenditure and FDI.
16. We are indebted with an anonymous referee suggesting us the set of controls to be included in the analysis. With the exception of the first group, i.e., R&D stock, GDP per capita, and HC, these controls are not usually included by the studies belonging to the international knowledge spillover literature.
17. We choose EPO data following Malerba *et al* (2013) and Bloom *et al* (2013), but our results are robust to using OECD data on applications to the USPTO, and are available upon request.
18. What we cannot fully control for is to which extent higher patenting might be induced by a change in the need of protection due to an increase in the GVCs participation of a country and not by international knowledge flows (i.e., a developing country might want to be more protected from MNEs the higher the involvement in GVCs and therefore increase the patent applications to increase protection for the same level of innovation performance).
19. R&D expenditure from World Development Indicators includes both private and public expenditure.
20. We use HC index from Penn Tables because it allows to keep a larger number of observations, but we also carried out our analysis by using a measure of education level—average years of education—from Barro and Lee database (Barro and Jong-Wha, 2013) as in Coe *et al* (2009). Barro and Lee database contains 5-year data, and we must use interpolation to get the missing years, but we still lose the last 4 years. In any case, results do not change even with the alternative HC index, and they are available upon request.
21. We have run the regressions of our preferred specifications in the baseline model (Columns 4 and 8, Table 2) by interacting the GDP per capita with year dummies to control for the business cycle and we have also run the same regressions by substituting the GDP per capita variable with the R&D expenditure as a share of GDP. Our results are all confirmed and available upon request. We are indebted with an anonymous referee suggesting us to check for the business cycle.
22. In the international knowledge spillover literature mentioned before, the exercise of fixing the weights is usually not implemented. We are indebted with an anonymous referee suggesting us to disentangle the two channels through which the spillover might be working.
23. It is worth noting that by fixing the GVC weights we neglect the large variation in the GVC participation patterns that occurred in the last decades, which is motivating our work.
24. We estimated all models considered in the paper, and not only the baseline, by fixing at the initial year either the GVC variables or the R&D stock of the partners: results confirm what emerged by the estimation of the baseline model. All the effect is driven by the variation in the GVC variables. Results are available upon request.
25. Since for us this is purely a robustness check, we use a standard gravity model for trade, despite the model to be used in estimating GVC bilateral flows is under discussion (Baldwin and Taglioni, 2014).
26. Countries in WIOD are 42, of which 28 are EU, plus the Rest of the World. Taiwan is not included in our analysis. Our split is based on WB classification. We build a lower-income group, based on lower-middle and upper-middle income economies in WB classification (we do not have lower-income countries since we do not have African countries in our sample), and a higher-income group, based on HI economies in WB classification.

HI countries: Austria, Belgium, Luxemburg, Netherlands, Sweden, Denmark, Spain, Finland, France, UK, Italy, Germany, Ireland, Japan, Australia, USA, Canada, Portugal, Greece, Switzerland, Norway, Croatia, Poland, Malta, Lithuania, Latvia, Korea, Estonia, Czech Republic, Slovakia, Slovenia, Cyprus, Hungary.
LI countries: Bulgaria, Romania, Turkey, Brazil, Mexico, India, China, Indonesia, Russia.

For robustness, we also carried out the analyses by splitting origin partners according to two other criteria which allow us to generate more balanced sub-samples: the median value of the GDP per capita in 1998 and the average years of education in 2000, computed from Barro–Lee data (2013). Results are robust and are available upon request.

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Appendix

Further Robustness Checks

Foreign value added in export and offshoring could also come from natural resources industries, which we expect to embody negligible amount of foreign knowledge and therefore to generate lower knowledge spillovers with respect to other industries. Therefore, we have run the regressions of the baseline model (Table 2) splitting our spillover variables, both the OFFIND and the FVSIND, into two variables for each indicator: one with the weights built from natural resource industries only and a second one with the weights built on the rest of the economy. Results show that the coefficient of the spillover variables excluding the natural resource industries is very close to the original ones, while the spillover from natural resources industries is never significant. Since the period we consider in the analysis includes the 2008 crisis, which affected trade volumes and GVC participation (Escaith *et al*, 2010), we also run the regressions of our preferred specifications (Columns 4 and 8, Table 2) by interacting the GDP per capita and the two spillover variables with a post-crisis dummy. Our results are confirmed. The results for both the checks are available upon request.

Supplementary Tables

See Tables 6, 7, 8, 9, 10 and 11.

Table 6: Models of international knowledge spillovers through GVC participation

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
R&D stock	1.063***	0.634**	0.618**	0.695**	1.034***	0.644**	0.629**	0.686**
	(0.314)	(0.285)	(0.284)	(0.268)	(0.320)	(0.286)	(0.285)	(0.270)
GDP per capita		1.375***	1.899***	1.817***		1.390***	1.921***	1.899***
		(0.369)	(0.565)	(0.548)		(0.370)	(0.569)	(0.568)
Human capital		1.312	1.613	1.329		1.293	1.593	1.376
FVSRD	3.517 (2.986)	−3.343	−3.613	−2.694				
		(2.255)	(2.279)	(2.685)				
OFFRD					3.883 (2.577)	−2.538	−2.827	−2.640
						(1.757)	(1.850)	(1.958)
Additional controls								
Population	No	Yes	Yes	Yes	No	Yes	Yes	Yes
FINRD	No	No	Yes	Yes	No	No	Yes	Yes
Inward FDI	No	No	Yes	Yes	No	No	Yes	Yes
Openness	No	No	Yes	Yes	No	No	Yes	Yes
DISTRD	No	No	No	Yes	No	No	No	Yes
FVS/OFF from residual group	No	No	No	Yes	No	No	No	Yes
	0.2365	0.4102	0.4178	0.4288	0.2432	0.4082	0.4160	0.4213
	510	510	510	510	510	510	510	510

Trade partners' composition fixed at 2000.
Note: dependent variable: patent per capita. All models include year and country FE. All variables are in logarithm and lagged 1 year. Standard errors are clustered at the country level. FVSRD is the stock of R&D of trade partners weighted by the foreign value added flows imported by partner on total export as in (7) in 2000. OFFRD is the stock of R&D of trade partners weighted by the offshoring index by partner as in (6) in 2000.
$^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$.
[a]Within R^2.

Table 7: Models of international knowledge spillovers through GVC participation

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
R&D stock	1.168***	0.699***	0.746***	0.802***	1.190***	0.737***	0.790***	0.840***
	(0.262)	(0.250)	(0.212)	(0.204)	(0.232)	(0.209)	(0.183)	(0.202)
GDP per capita		1.402***	1.467***	1.526***		1.334***	1.438***	1.470***
		(0.364)	(0.316)	(0.289)		(0.350)	(0.302)	(0.278)
Human capital		1.193 (1.541)	1.097 (1.631)	1.034 (1.664)		1.016 (1.491)	0.691 (1.615)	0.606 (1.610)
FVSRD	0.703***	0.650***	0.947***	0.844***				
	(0.225)	(0.178)	(0.253)	(0.244)				
OFFRD					0.858***	0.750***	1.116***	1.079***
					(0.281)	(0.244)	(0.268)	(0.258)
Additional controls								
Population	No	Yes	Yes	Yes	No	Yes	Yes	Yes
FINRD	No	No	Yes	Yes	No	No	Yes	Yes
Inward FDI	No	No	Yes	Yes	No	No	Yes	Yes
Openness	No	No	Yes	Yes	No	No	Yes	Yes
DISTRD	No	No	No	Yes	No	No	No	Yes
FVS/OFF from residual group	No	No	No	Yes	No	No	No	Yes
R^{2a}	0.2765	0.4450	0.4661	0.4730	0.3165	0.4706	0.5051	0.5090
N	510	510	510	510	510	510	510	510

Partners' R&D fixed at 2000.
Note dependent variable: patent per capita. All models include year and country FE. All variables are in logarithm and lagged 1 year. Standard errors are clustered at the country level. FVSRD is the stock of R&D in 2000 of trade partners weighted by the foreign value added flows imported by partner on total export as in (7). OFFRD is the stock of R&D in 2000 of trade partners weighted by the offshoring index by partner as in (6).
$^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$.
[a]Within R^2.

Table 8: Gravity models

	OFF	*FVS*	*OFF*	*FVS*
R&D stock (origin)	0.250***	0.132***	0.291***	0.161***
	(0.075)	(0.051)	(0.079)	(0.054)
R&D stock (destination)	0.006	0.055	0.022	0.078
	(0.075)	(0.056)	(0.077)	(0.057)
Real GDP (origin)	1.183***	1.341***	1.155***	1.324***
	(0.113)	(0.079)	(0.117)	(0.082)
Real GDP (destination)	−0.148	−0.339***	−0.213*	−0.374***
	(0.115)	(0.080)	(0.116)	(0.081)
Distance			−1.341***	−0.970***
			(0.044)	(0.029)
Colonial relationship			0.465***	0.309***
			(0.129)	(0.090)
Contiguity			0.133	0.240***
			(0.115)	(0.087)
Common language			−0.045	−0.004
			(0.124)	(0.087)
Fixed effects				
Year	Yes	Yes	Yes	Yes
Destination country	Yes	Yes	No	No
Origin country	Yes	Yes	No	No
Destination × origin	No	No	Yes	Yes
R^2	0.0744	0.1621	0.4714	0.5466
N	23,294	23,294	23,294	23,294

Note: dependent variables: bilateral flows [offshoring as in (6) and foreign value added as in (7)]. Origin country is the country from where inputs/foreign value are imported by the destination country. All variables are in logarithm. Standard errors are clustered at the origin–destination level.
$^{*}p<0.10$, $^{**}p<0.05$, $^{***}p<0.01$.
[a]Within R^2.

Table 9: Sample descriptive statistics

Variables	*Obs*	*Mean*	*Std. dev.*	*Min*	*Max*
Patent per capita (log)	510	−10.794	2.131	−17.655	−7.708
FVSRD (log)	510	25.185	0.660	23.379	26.964
OFFRD (log)	510	24.860	0.723	22.990	27.096
R&D stock (log)	510	24.075	2.028	18.462	28.578
Human capital (log)	510	1.108	0.161	0.578	1.313
GDP per capita (log)	510	10.151	0.624	7.833	11.462
Population (log)	510	16.741	1.839	12.896	21.024
FINRD (log)	510	24.418	0.522	22.911	25.929
DISTRD (log)	510	21.391	0.607	19.674	22.666
Openness (log)	510	−0.325	0.530	−1.657	1.203
FDI net inflows per cent of GDP (log)	510	1.207	1.372	−6.523	6.113
FVS from residual group (log)	510	−3.145	0.462	−4.527	−1.825
OFF from residual group (log)	510	−3.283	0.471	−4.575	−2.074

Table 10: Cross-correlation table

Variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*
(1) Patent per capita	1.00												
(2) R&D stock	0.31	1.00											
	(0.00)												
(3) FINRD	0.28	−0.25	1.00										
	(0.00)	(0.00)											
(4) DISTRD	0.53	−0.14	0.57	1.00									
	(0.00)	(0.00)	(0.00)										
(5) FVSRD	0.22	−0.22	0.80	0.52	1.00								
	(0.00)	(0.00)	(0.00)	(0.00)									
(6) OFFRD	0.24	−0.24	0.86	0.53	0.95	1.00							
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)								
(7) FVS from	−0.26	−0.12	0.03	−0.16	0.25	0.10	1.00						
residual group 1	(0.00)	(0.00)	(0.41)	(0.00)	(0.00)	(0.01)							
(8) OFF from	−0.39	−0.24	0.02	−0.24	0.13	0.08	0.89	1.00					
residual group 1	(0.00)	(0.00)	(0.65)	(0.00)	(0.00)	(0.04)	(0.00)						
(9) Inward FDI	0.07	−0.38	0.32	0.28	0.30	0.33	0.01	0.05	1.00				
	(0.09)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.87)	(0.25)					
(10) Openness	0.23	−0.63	0.65	0.68	0.64	0.64	0.08	0.06	0.53	1.00			
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.06)	(0.14)	(0.00)				
(11) Human capital	0.67	0.13	0.32	0.47	0.09	0.16	−0.31	−0.36	0.04	0.26	1.00		
	(0.00)	(0.00)	(0.00)	(0.00)	(0.03)	(0.00)	(0.00)	(0.00)	(0.33)	(0.00)			
(12) GDP per capita	0.87	0.16	0.40	0.52	0.26	0.36	−0.33	−0.38	0.12	0.29	0.69	1.00	
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
(13) Population	−0.34	0.77	−0.47	−0.49	−0.37	−0.42	0.10	0.06	−0.41	−0.77	−0.36	−0.46	1.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)	(0.18)	(0.00)	(0.00)	(0.00)	(0.00)	

Table 11: Variables and sources

No.	*Indicators*	*Sources*
1	Patent per capita; patent applications to the EPO, by inventors' country of residence and priority date	OECD–EPO (OECD, 2017)
2	GDP per capita: GDP converted to international dollars $ using PPP rates international $), divided by total population	Constant 2011 World Bank (WDI)
3	Human capital: Human capital index, based on years of schooling and returns to education; see Human capital in PWT9	Penn World Tables, 9.0 (www.ggdc.net/pwt) (Feenstra *et al*, 2015)
4	Population	World Bank (WDI)
5	Openness: sum of total export and total import over GDP	http://WIOD.org (Timmer *et al*, 2015)
6	R&D stock: computed with the perpetual inventory method by using R&D expenditure flows as per cent GDP	World Bank (WDI)
7	FDI inflows: Foreign direct investments net inflows (per cent GDP)	World Bank (WDI)
8	FVSRD: stock of R&D of trade partners weighted by the foreign value added flows imported by partner on total export as in (7)	http://WIOD.org (Timmer *et al*, 2015) and World Bank (WDI)
9	OFFRD: the stock of R&D of trade partners weighted by the offshoring index by partner as in as in (6)	http://WIOD.org (Timmer *et al*, 2015) and World Bank (WDI)
10	FINRD: the stock of R&D of trade partners weighted by imported of final goods as share of total final goods index, by partner	http://WIOD.org (Timmer *et al*, 2015) and World Bank (WDI)
11	DISTRD: the stock of R&D of all countries weighted by the inverse of the geographical distance	CEPII GeoDist database (Mayer *et al*, 2011) and WB
12	FVS from residual group: is the foreign value added flows computed as in 4 from a residual group of countries (Rest of the World and Taiwan)	http://WIOD.org (Timmer *et al*, 2015)
13	OFF from residual group: is the offshoring index computed as in 1 from a residual group of countries (Rest of the World and Taiwan)	http://WIOD.org (Timmer *et al*, 2015)