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DISSERTATION

Essays on the Impact of Technological Change on Economic Structure

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Declaration of Authorship

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Abstract

This dissertation investigates the interplay between technological change and economic structure. Welcomed technological change sometimes brings changes to the structure of the economy which introduces not so welcomed economic frictions. On the other hand, economic structure can foster or hinder technological change. This thesis focuses mainly on structural changes such as R&D financing and global value chain (GVC) integration potentially translating into economic productivity.

In Chapter 2, I show that business R&D spending exerts both direct and indirect positive effects on value added. Nevertheless, the heterogeneity of the returns to R&D has seldom been examined. Using detailed sectoral data from Czechia over the period 1995-2015, this study finds that privately funded business R&D has both direct and spillover effects, but that the publicly funded part of business R&D only leads to spillovers. The results further suggest that both upstream and downstream spillovers matter, regardless of the source of funding, and that during the period studied, R&D returns were heavily affected by the economic crisis. Lastly, private R&D offers significant returns only after reaching a critical mass, while the effects of public R&D spending do not display such non-linearity. This heterogeneity in the returns to business R&D should be reflected in innovation policy design.

In Chapter 3, I investigate whether GVC participation provides benefits in terms of greater specialization and technology diffusion and whether these benefits are homogeneous across countries and industries. The chapter shows that taking into account functional specialization helps to explain how the benefits of GVC participation are distributed. Using data for 35 industries in 40 countries in 2000-2011, we estimate the impact of GVC participation on value added within a production function framework. The results indicate that there is heterogeneity in the effects of GVC participation, according to the functional specialization of the respective industry and its GVC partners. Participating in R&D-related GVCs is especially profitable for fabrication-oriented industries and low-developed countries. It follows that any GVC participation analysis will be incomplete if it fails to take the functional specialization of the GVC participants into consideration.

In Chapter 4, I deal with how GVC participation and R&D spending complement one another. Since value-added distribution along the production chain is unlikely uniform and since the hierarchy of the chain depends on technological capabilities, I hypothesize that greater R&D prowess will also spur greater benefits from GVC participation. Using data from the World Input-Output Database and combining it with R&D expenditures of 49 Czech industrial sectors over the 2000-2014 period, I show that the benefits of GVC participation are indeed not identical between industries and that GVC participation benefits are stimulated by R&D stock of the respective sector.

JEL Classification	O32, O33, O47, L14, F02, F14
Keywords	research and development, global value chains, technology transfer, foreign direct investment
Title	Essays on the Impact of Technological Change on Economic Structure

Abstrakt

Tato disertační práce zkoumá vzájemný vztah mezi technologickými změnami a ekonomickou strukturou. Vítané technologické změny někdy přinášejí změny ve struktuře ekonomiky, které přinášejí ne příliš vítané ekonomické frikce. Na druhé straně může právě ekonomická struktura technologickou změnu stimulovat nebo jí bránit. Tato práce se zaměřuje především na strukturální změny, jako je financování R&D a integrace do globálních hodnotových řetězců (GVC), které se potenciálně promítají do ekonomické produktivity.

V kapitole 2 ukazuji, že podnikové výdaje na výzkum a vývoj mají přímý i nepřímý pozitivní vliv na přidanou hodnotu. Nicméně heterogenita výnosů z výzkumu, vývoje a inovací byla zkoumána jen zřídka. Na základě podrobných odvětvových dat z Česka za období 1995-2015 zjišťuji, že soukromě financovaný podnikový výzkum a vývoj má přímé i vedlejší činky, ale že veřejně financovaná část podnikového výzkumu a vývoje vede pouze k vedlejším efektům. Výsledky dále naznačují, že jak vedlejší efekty směrem k dodavateli, tak směrem ke spotřebiteli jsou důležité bez ohledu na zdroj financování a že ve sledovaném období byly výnosy z výzkumu a vývoje silně ovlivněny hospodářskou krizí. A konečně, soukromě financovaný podnikový výzkum a vývoj přináší významné výnosy až po dosažení kritického množství, zatímco dopady veřejných výdajů na výzkum a vývoj takovou nelinearitu nevykazují. Tato heterogenita výnosů z výzkumu a vývoje v podnicích by měla být zohledněna při tvorbě inovační politiky.

V kapitole 3 zkoumám, zda účast v GVC přináší výhody v podobě větší specializace a šíření technologií a zda jsou tyto výhody homogenní napříč zeměmi a odvětvími. Kapitola ukazuje, že zohlednění funkční specializace pomáhá vysvětlit, jak jsou přínosy účasti v GVC rozděleny. Na základě údajů pro 35 odvětví ve 40 zemích v letech 2000-2011 odhadujeme dopad účasti v GVC na přidanou hodnotu v rámci produkční funkce. Výsledky ukazují, že existuje heterogenita v dopadech účasti v GVC v závislosti na funkční specializaci příslušného odvětví a jeho partnerů v GVC. Účast v GVC souvisejících s výzkumem a vývojem je výhodná zejména pro odvětví zaměřená na výrobu a pro málo rozvinuté země. Z toho vyplývá, že jakákoli analýza časti v GVC bude neúplná, pokud nezohlední funkční specializaci účastníků GVC.

V kapitole 4 se zabývám tím, jak se čast v GVC a výdaje na výzkum, vývoj a demonstrace vzájemně doplňují. Protože rozdělení přidané hodnoty v rámci výrobního řetězce není pravděpodobně rovnoměrné a protože hierarchie řetězce závisí na technologických schopnostech, předpokládám, že větší zdatnost v oblasti výzkumu a vývoje bude také podněcovat větší přínosy z účasti v GVC. Na základě údajů z World Input-Output Database a jejich kombinace s výdaji na výzkum a vývoj 49 českých průmyslových odvětví v období 2000-2014 ukazuji, že přínosy účasti v GVC skutečně nejsou mezi odvětvími stejné a že jsou stimulovány stavem výzkumu a vývoje v příslušném odvětví.

Klasifikace JEL	O32, O33, O47, L14, F02, F14
Klíčová slova	výzkum a vývoj, globální hodnotové řetězce, přímé zahraniční investice, technologická výměna
Název práce	Eseje o vlivu technologické změny na strukturu ekonomiky

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Chapter 1

Introduction

One of the curious tasks of economics is to figure out where economic growth comes from and discover tools that would stir it in places suffering from economic sluggishness. Early classical economics expressed awe at the merits of economic specialization and described how hurdles to free market can hinder economic efficiency and thus a perspective of long-term growth (Smith 2010). Letting people trade freely means they can specialize and become much more efficient at a single task than they would be, had they tried to master many.

The increasingly sliced tasks of production require (as with any other economic activity) certain quantities and qualities of labor and capital and suitable technology that ties the factors of production together. Such conceptualization gave birth to various models which attempt to show where economic growth comes from and what can be done to nurture it. Exogenous growth models such as the textbook version of the Solow-Swan model (Solow 1956) show how catch-up per-capita growth can happen through capital accumulation. The economic growth of economies whose capital accumulation reaches a steady state, however, remains unexplained by the model.

Capital accumulation is relevant to the policymaking of many countries. Spending on the "means of production" as opposed to the consumer products was also one of the strategies of the command economy of the Eastern bloc Maddison (1998). Indeed, the rapid capital accumulation linked to industrialization bore fruit at first. However, reaching the tipping point where the marginal benefit of additional investment is outweighed by its costs puts a stop to such a growth model (Solow 1956). The logic of upstream investment which would then stir the production of downstream goods was flawed. More lumber mills do not necessarily lead to toilet paper availability. Catching up with the economic forerunners and leading the economic growth are indeed two separate goals requiring different conceptualizations and adjusted policies.

Technological leaders can not rely on capital accumulation. The economic growth is driven by technological progress, enhancing human capital or quality of institutions. [1] Mainly because of their fuzziness, the concepts of institution quality did not make it into the standard economic models. Their importance was proven through economic inquiry (North 1989), but it remains difficult to incorporate institutional quality into mathematical models, mainly because of the difficulty of measuring institution quality in a way which is comparable in time and across countries.[2]

This is not the case for human capital and technology. The first models which considered technology growth to be endogenous to the production function simply lumped technology and human capital together (Uzawa 1965). Later, innovation-based models made a distinction between technology and physical and human capital (Romer 1990). Whereas human capital is accumulated by schooling and the physical one by saving, productivity increases with innovation. The model employs Dixit-Stiglitz-Ethier production function. Innovation increases product variety which spreads the production across a greater spectrum of products and because of the diminishing returns to employing intermediate products the overall production become more effective. Such reasoning is not dissimilar from the observation of Adam Smith about the benefits of specialization.

Yet another step towards a more detailed description of the origins of innovation comes from Schumpeterian growth models such as Aghion & Howitt (1990) or Grossman & Helpman (1994). There, the innovation process is stochastic, depends on R&D spending, and the model also recognizes the increasing complexity of knowledge and thus the diminishing returns to unit R&D spending. These efforts show how important role technology plays in the economy, or at least in the minds of the economists. In the empirical inquiry into the drivers of economic growth, the concept of technology is fuzzier, and the list of its potential drivers is longer.

The empirical studies often label everything we cannot measure in the framework of production function as technology (Van Beveren 2012). Indeed, Abramovitz (1993) coined the total factor productivity (TFP) as "the measure

[1]Culture, religion, and other informal institutions are often investigated separately but broadly speaking, they fall into the category of social technology or institutions.

[2]Despite the difficulty, there has been attempts of doing so. The models, however, did not make it into the mainstream.

of our ignorance". Variables other than capital and labor diminished the residual of the production function and thus TFP, but the explanatory power was far from satisfactory. Brinkman (1995) even scolded some of the endeavors of looking into the black box of TFP with a quip: "...while Scott did indeed look into the black box, he forgot to bring a flashlight". Reflecting the progress of last decades, such an assessment seems a bit too harsh. Since the inception the TFP concept, successful attempts have been made which show how changes in TFP can be explained by various factors: among others R&D (Hall 2006), human capital (Benhabib & Spiegel 2005; 1994; Vandenbussche *et al.* 2006), openness to trade (Danquah *et al.* 2014) or entrepreneurship (Aparicio *et al.* 2016).

Some of the drivers are considered in the endogenous growth models, but some are omitted. Social capability which is also essential in production is notably not explicitly considered by the theoretical models or is just implicitly lumped together with the rest of the technologies. It is understandable as social institutions are more elusive (Abramovitz 1986). Their dynamics make them suitable for comparative analysis of how things are (Robinson & Acemoglu 2012), but they are less fit to serve in models calibrated using relatively frequent data with greater than country-level granularity. The changes in social institutions are more difficult to proxy with quantitative variables, especially compared to the production technology which can be approximated, e.g., by R&D spending or the number of patents.

The well-established drivers such as R&D can be influenced by public policy and thus it is likely that economic catching-up can be influenced by policy too. Since economic convergence of countries differ (Romer 1990; Grossman & Helpman 1990; Griliches 1998; Keller 2004; Lee & Tan 2006; Hidalgo *et al.* 2010), it is likely that smarter policy leads to better economic results through improving technology. Moreover, it seems that technological change plays a greater role in economic development than capital accumulation (Badunenko *et al.* 2008) which is hardly surprising in the case of countries abundant with fixed capital. Abstracting from improving social institutions and admitting that capital accumulation can no longer be the driver of economic growth, policymakers aiming to increase economic productivity can turn to technological progress.

Technological progress is related to or even derived from research and development (R&D). R&D is itself very heterogeneous, and it is difficult and misleading to consider all its varieties to produce qualitatively similar technological leaps. Even the recipients of the benefits of R&D differ. Whereas firms are mainly interested in development or applied research which can be put to use as soon as possible in their production process, policymakers should be interested in more general technologies, and thus should finance basic research which provides benefit across firms and industries and despite its social benefits is difficult to capitalize on directly. The logic behind the various forms of public support to the business to R&D, whether it is tax policy or direct subsidies, or public funding of R&D done in public institutions is to increase R&D investment to levels optimal to the whole economy, not just to individual firms. The goals are increased economic efficiency, growth, and technological advancement.

R&D can either make the production process more efficient or come up with brand new products. New products can naturally create huge shifts in the markets, putting some firms out of business and creating significant market opportunities for complementary products. Yet process innovation may prove equally disruptive if the change in the relative prices of products leads to significant factor allocation. Depending on the kind of market, the benefits of either process or product innovation are divided between the firms and customers.

In the case of firms, the effects of one innovating firm on another can be twofold: it either benefits from goods and services whose greater quality is not fully reflected in the increased price, or the related business can benefit from the technology itself â€“ the related firm can simply learn it. Such knowledge spillovers can be detected between firms, industries, and countries. The dynamics of the spillovers are less clear, however. They could be the function of the technology gap, and in extreme cases, they surely are. However, the existing technology employed by the receiving entity also defines the absorptive capacity and thus the potential for knowledge spillover.

Data for R&D is widely available and comparable across countries. We thus have estimates of the R&D spending effects on the country's productivity (Hall *et al.* 2010), indirect R&D returns (Lucking *et al.* 2018). The evidence quite decisively suggests that both direct and indirect returns to R&D are, despite their heterogeneity, positive across the board. We even see how R&D prowess serves as an enabler of technology transfer for the receiving countries (Teixeira & Fortuna 2010). Domestic R&D capacities can partially explain the heterogeneity of countries' development as well as their capability for adopting the frontier technology of their trading partners.

The returns to R&D are also not constant over time. Whereas the progress of the industrial revolution was often driven by extraordinary characters who invented machines transforming the world, the progress of today is rather driven by huge research teams and international effort. The number of researchers and engineers engaged in R&D goes up, yet the economy does not get increasingly more innovative â€" at least if we assume that innovativeness should be eventually reflected in economic growth. In other words, the cost of coming up with a new innovative idea went up. Bloom *et al.* (2020) argue that the returns to R&D indeed decrease over time and that in order to sustain a steady level of economic growth, the resources used in producing innovation must increase. They use examples from computer chip production, crop yields, to pharmaceutical research.

It is not clear, however, whether the dissemination of the new technology gets harder or easier over time. The complexity of the technology suggests it might be more difficult. Implementation of cloud technologies, for instance, requires greater preexisting knowledge than adoption of typing machines. On the other hand, the availability of information and the infrastructure for its sharing is unparalleled in history. One needs knowledge about IT systems and cloud architecture to use it to her benefit, but such information is mostly readily available online. Moreover, the rate at which the whole population adopts technology seems to increase as well. DeGusta (2012) used a phone to illustrate that. The rate at which consumers adopted landline was dwarfed by that of mobile phone adoption which again was humbled by the rate of smartphone adoption.

The adoption of technology related mostly to production (such as robotics) is somewhat different. Whereas the purchase of a smartphone does not require the consumer to have a landline, robotization of the production line requires having advanced technology to begin with, not to mention the specifically qualified staff. This is not the reason why robotization happens mostly in already industrialized countries (labor costs are likely far more important factor) but it is and an additional reason for economies to build their industrial know-how. Unlike in consumer goods, it is not as easy to leapfrog and get into to front of the technological pack. Technology adoption at the industrial level requires necessary absorptive capacity in terms of preexisting technology and human capital. Attempts of transferring technology from one place to another without the necessary prerequisites proved naive (Baldwin 2016)).

The steady road of technological upgrading can be fostered by own R&D efforts, but also by adopting existing technology from abroad. When countries trade goods and services, they also exchange knowledge and ideas about production processes and technology. This can lead to technology spillovers, where the knowledge and technology of a more technologically advanced country spills over to less advanced countries, contributing to economic development and growth. For example, a less developed country that imports a new technology can learn from the technology and apply it in its own production processes, leading to improvements in productivity and efficiency (Castellacci 2011; Danquah *et al.* 2014; Botric *et al.* 2017). However, the trade itself changes. There has been only a vague notion of how a more recent transformation of international trade cooperation, global value chains (GVCs), contributes to the dissemination of technology and thus to economic catching-up. Rodrik (2018), for instance, suggests that GVC participation and technology does not lift all the boats and the effects are thus heterogenous with a potential of harming the developing economies.

GVC participation requires a more nuanced approach. With strict hierarchy between the GVC agents, even improved R&D capabilities may not help the country to take responsibility for more complex tasks and thus obtain greater value added (Grossman & Rossi-Hansberg 2008; Gereffi *et al.* 2005). Distribution of tasks along the value chain influences for both value-added distribution and technology transfer. Investigating only GVC participation thus pools two effects together: the technological and the hierarchical. Whereas it is hard to imagine that international trade, even in its value chain form, can cause technological drawbacks, it is possible to imagine that hierarchical international trade may be a hindrance in country development. As a supplier, one can become more productive at a production of the specific product, but it may be very difficult to move up in the production chain and obtain a greater share of the total value added (Humphrey & Schmitz 2002). This may be especially the case for developing countries that are not focused on tasks associated with high valued added (R&D, marketing, headquarter activities) as they lack the multinational corporations which usually sit at the center of the value chain (Gereffi *et al.* 2005).

The value chain hierarchy logic lends an additional argument for a more pronounced industrial policy. The traditional concept of international trade suggests that seamless trade leads to greater efficiency and possibly greater technology transfer. Several international trade policies can help to facilitate technological progress. Policies such as tariff reductions should increase the incentives for firms to invest in R&D by making it more profitable to produce and sell new and innovative products. Lower tariffs should also reduce the costs of imported inputs and technologies, making it easier for firms to access new technologies and improve their productivity. Similarly, FDI could help to transfer technology and knowledge between countries (Braconier *et al.* 2001). When firms invest in foreign countries, they may bring new technologies and production processes with them, which can help to improve the productivity of the host country. However, value chains introduce greater heterogeneity into international trade and with that also the possibility to get and eat greater or lesser share of the growing pie.

Consideration of the inequality embedded into the value chains along with worries about value chain resilience and national security has caused the great return of the industrial policy. Governments around the globe intervene in international trade through tariffs, subsidies and regulations. Even the former champions of free trade use such a policy with considerably heavy hand. This is not to say, however, that we are returning to the protectionist era. The current industrial policy does not aim at curbing international trade, it rather seeks to redirect it. Instead od deglobalization, we rather witness decoupling.

For instance, the Biden administration continues the trend of reducing American economic dependence on China. This does not mean, however, that all the affected industries will be reshored back to the United States. In many cases, it can rather mean diversification of trade where American customers seek suppliers in other countries. In some instances, international cooperation is necessary for the goals of national industrial policy. The production of semiconductors is a very concentrated industry. If the United States seek to create secure production chains of semiconductors and potentially limit Chinese access to it, cooperation with countries such as Korea, the Netherlands, Belgium, and most importantly Taiwan is crucial.

There are flavors of industrial policies that are outright harmful to international trade. Conditioning a subsidy on the requirement about the origin of a certain part of the product (electric car or batteries, in many cases) leads to inefficiencies in global production. But the analysis of the severed and newly created value chains may provide insights about the winners and losers of such policy. The distribution of effects may actually be of greater use than the estimation of the overall effect. Since such policies are motivated by environmental and security considerations whose benefits can be hardly estimated, estimating their costs is of limited use.

As industrial policy comes back into vogue, the implications of our findings are increasingly relevant. Ideas such as strategic autonomy may have to be assessed more broadly. As this thesis suggests, the effects of such policies may vary country from country, industry from industry, and may depend upon a variety of confounding factors. The same applies to the development policies of non-OECD countries. We add to the vast body of literature that provides a comprehensive account of how industrial policy specifically focused on fostering or stifling international cooperation in one way or another makes a huge difference in the respective countries' fortunes (Harrison & Rodríguez-Clare 2010; Stiglitz *et al.* 2013; Warwick 2013; Aghion *et al.* 2015). It should be stressed, however, that the current knowledge describes technological framework of today. Baldwin *et al.* (2014) foretells the third unbundling (after industrial and ICT revolutions), which may change the rules of the game entirely.

Apart from the risk of not describing the world of tomorrow, our approach has naturally other limitations. The main obstacle lies in the specification which does not allow for a causal interpretation. Thus, the results have solely explorative character. This is caused by the current unavailability of more detailed data which would allow for claims of causality. The limitation of the data also restricts the number of concepts it is possible to investigate empirically. As mentioned above, social capability or absorptive capacity are very rich notions that, sadly, have to be only approximated by quantitative measures such R&D capital stock, FDI stock, or functional specialization. The research is thus only hinting at the links between the greater notions, potentially missing the most important interplays which are, due to data unavailability, omitted.

This is something, which can be improved upon greatly. There is an increasing amount of data being collected privately, in firms that focus on supply chains, and international trade. Such data can be increasingly used in the more elaborate model specification which would get closer to proper causal identification. Similarly, covid pandemic presents itself with a myriad of exogenous shocks which can be used in quasi-experimental designs to see, for instance, whether GVC participation really causes economic development or whether it merely accompanies it.

This thesis covers technology transfer in three stages. First, I investigate R&D returns, both their direct and indirect kinds. Second, I inspect GVC participation and its links to sectoral productivity. Lastly, I bridge these two papers with an inquiry into the catalysts of technology transfer, specifically whether the R&D and FDI can stimulate the benefits which GVC participation provides.

Chapter 2 – *Heterogeneity of Returns to Business R&D: What Makes a Difference?* begins the inquiry into technology transfer by estimating R&D returns to in Czechia. Apart from estimating direct R&D returns which surprisingly has not been done for Czechia, spillover effects are also estimated with respect to specific channels. I thus distinguish between spillovers from privately and publicly funded R&D, whether they happen in upstream or downstream directions of the production process. It is important to have such estimates as R&D spending should reflect not only the direct gains of the spender but also the aggregate social benefits which are impossible for the spender to monetize. Such distinctions are not common in the literature and are especially novel in the Czech context.

To estimate the R&D returns, I follow Hall *et al.* (2010) and construct the R&D stocks from annual R&D spending data. I then use the standard Cobb-Douglas production function to get a regression equation yielding the final estimates. Such approach allows for calculating the public and private R&D stock separately. I further use input-output tables to estimate the links between sectors with the assumption that intensive trade links can be used for technology transfer (Eberhardt *et al.* 2013). I calculate shared R&D stock which is R&D stocks of other sectors weighted by the linkages obtained from the input-output data. The structure of the input-output data allows to further distinguish between the forward (downstream) and backward (upstream) links.

I find that privately funded business R&D has positive direct effects whereas publicly funded business R&D spending benefits the economy mainly indirectly, via spillovers. However, the direct effects of privately funded business R&D are also positive and statistically significant. Estimates of the spillovers which happen through forward and backward linkages show that the technology transfer happens in both directions, although the forward link is the more prevalent one. Furthermore, there seems to be a critical mass required, so that the return of privately funded business R&D can materialize. This is not the case for publicly funded R&D. The returns to R&D do not stay intact over time. The financial crisis affects the estimates significantly. While the returns to private business R&D soared during the crisis (selection bias might be a chief culprit, as those who managed to keep their R&D spending up were likely those, who were less affected by the crises), the returns to publicly funded R&D turned negative - possibly because of R&D support being used as fiscal help for those most severely hit by the crisis.

The results of this chapter show that the most straightforward proxy for technology, R&D, indeed relates to value-added and that such a form of technology that dissipates through the economy is hardly trivial. Moreover, the dissipation can be strongly influenced by policy – by public spending but also through creating an environment where tacit knowledge spreads faster and more efficiently. The policies should be also weighted against each other as R&D subsidies for firms, tax credit related to R&D or direct public R&D spending are likely to yield different results. Public R&D expenditures taken as an aggregate variable thus may not provide sufficient detail.

Chapter 3 – *Who Benefits from Global Value Chain Participation? Does Functional Specialization Matter?* focuses rather on international technology transfer, specifically, on the effects of GVC participation. There is ample evidence that international contact can be good for technology diffusion (Schneider 2005) but the novel organization of trade, namely GVCs, poses a new question of whether the technology diffusion happens across the whole chain and whether the improvements in productivity are not offset by the effects of stringent GVC hierarchy which is often embedded in the GVC organization.

That the distribution of value added is not distributed evenly across the production chain and that the distribution has a U-shape has been known for decades (Shih, 1992). But the effects of GVC participation based on the role of that the country, industry or a firm plays and the role its partners in chain has been neglected. Using functional specialization at the industry level, I estimate the relations between value-added and a particular kind of GVC participation. I can thus distinguish between GVC participation related to R&D, fabrication, and marketing which, to my knowledge, has not yet been done. The amount of transferable knowledge can vary between the functional specialization as well as it may depend on the functional specialization of the GVC partner. Because of the U-shape of the value-added distribution, I focus mainly on fabrication as those specialized in this business function. Indeed, this is the stage with the least capabilities and prone to absorb the most technology from international contact. It should be noted that functional specialization is a term used both with respect to firm and industry. Whereas at the firm level, it refers to the distribution of tasks along the production process, at the industry level, we refer to more broadly defined areas of employee engagement.

Empirically, foreign value-added share obtained from input-output tables serves as the proxy for GVC participation. The estimation strategy uses the standard Cobb-Douglas production function, similarly to other researchers (Kummritz *et al.* 2017). The benchmark estimates show a positive relationship of GVC participation and value-added. Not the whole relationship can be attributed to technology transfer. The causality likely works both way and the hierarchical effects of GVC participation surely play a role too. This is confirmed by the crucial finding that GVC participation benefits increase with fabrication specialization. Since fabrication is not associated with a dominant role in the GVC hierarchy, it is sound to assume that technology transfer (though not necessarily in the intentional and codified way) is especially present in such a setting.

Focusing on the functional specialization of the GVC partner, I have found that GVC partners linked to marketing are the least beneficial. This again confirms the theories of strict GVC hierarchy with a central firm controlling the whole value chain, but particularly the sales. Being a mere contractor is thus not as profitable role in a GVC – a finding in line with existing evidence (Stöllinger 2021). From the perspective of fabrication-oriented industries, it is GVC partner focused on R&D that provides an additional benefit of GVC participation. The attention to business function overshadows the country dimension of the GVC organization. I hypothesize it, and rightly so – country differences are mainly due to their distinct business focus, not due to some other underlying characteristics. That said, there is still some remaining, and not surprising heterogeneity. Low-developed countries disproportionately gain from contract with R&D focused GVC partners. Contrarily, dealing with fabrication-oriented partners yield small benefits for them than it does to high-developed countries. Because GVCs are often organized within a single industry, I also investigate the benefits intra-industry GVC participation links to value added. Indeed, the benefits of intra-industry GVC participation are significantly greater than those of its inter-industry kind.

I have successfully shown that there is indeed technology transfer happening through GVCs and that the intensity by which it happens is likely heterogeneous. The implications for industrial and trade policies of both developed and developing nations are significant. For instance, the realization that GVC participation with R&D focused partners yields benefits to everyone, but especially to fabrication-oriented industries serves as an argument for trade openness of the developing countries. There are, however, more policies that could affect the absorption capacity of a country and thus enhance the technology transfer happening within GVCs.

Chapter 4 – *Heterogeneity of GVC Participation Effects and Its Catalysts* delves more into the drivers of the technology transfer. Bridging the insights from the two previous chapter, I inspect how R&D affects the relationship of GVC participation and value added. R&D stock is a decent measure of technological competencies which define both absorption capacity as well as prerequisites for optimal positioning within GVCs. It has been established in chapter 2 that R&D has both direct and spillover effects. This chapter develops this argument even further by showing that R&D can be a conduit of positive effects of other phenomena, such as GVC participation or FDI. FDI being one of the modes of GVC participation only with tighter links and stricter hierarchy, it is an ideal comparison for the results that the standard proxy of GVC participation, foreign value-added share, yields.

The international trade-R&D-productivity nexus has been investigated (Teixeira & Fortuna 2010; Ali *et al.* 2017). However, GVCs, to my knowledge, enter the picture for the first time in this paper. I build on the previous papers both with respect to data and methods. I restrict the analysis to the Czech data, so the results admittedly have limited external validity. Despite that, the analysis provides interesting results as it shows that R&D stimulates the benefits from GVC participation only with developed countries. The findings are quite intuitive as they suggest that it is mainly the technology transfer which benefits Czech industries through GVC participation with more developed countries. There is no evidence for capability build-up through R&D spending and subsequent dominance in GVCs containing less developed countries in the Czech context. Interestingly, the empirical analysis also finds that R&D does not stimulate the returns to inward FDI suggesting that stricter hierarchy leaves less space for other conductive factors such as absorptive capacity.

Understanding technology transfer is difficult task. Concepts that we use are constantly in flux. GVCs may be the most recent phenomenon, but it is not difficult to imagine a different organization of international trade. Baldwin *et al.* (2014) envisages the possibility of easy quasi-physical personal transportation which can bring about the new unbundling. Yet, even partial understanding of how technology is created, how it affects the economy and how it spread between countries and industries stimulate efficient policies which in turn stimulate economic growth. And economic growth is the tool for solving other pressing economic, social, and environmental issues. I hope my essays contribute in their modest manner to these noble ends.

The empirical approach of this thesis is defined by the problem it investigates. Concept of technology transfer is broad with many underlying driving factors. It is thus very difficult to pinpoint a causal relationship that would neatly fit the narrative of technology being transferred through GVC participation. This thesis, however, does not even aim at such a lofty goal. It rather investigates potential links between phenomena which cannot serve as a robust and definitive empirical evidence but can be nonetheless useful for policy makers.

Such approach is no longer mainstream in the top economic research. In my opinion, the focus on economic profession has shifted from great question with modest answers to modest questions with great answers. With respect to academic rigor, this has been a very positive shift. Proper identification of causal relationship, experimental approach and usage of microdata gives economists warranted confidence about their policy recommendations. As of now, the number of new reasonable policy recommendation dwarves the number of implemented policies.

A good example is paper by Bauer (2022). It investigates very narrow question of how provision of non-invasive information can cause people to change their behavior to their benefit and to benefit of others. Specifically, it shows how telling people the real opinion of doctors about vaccination can increase vaccination rate. Its experimental design gives it a great internal validity and its findings are relevant beyond the realm of public health. Yet, the problems with which policy makers deal are not limited to those where robust economic evidence is available.

Evidence-based policy making is often unachievable goal. The concept is thus often replaced by information-based policy making. Realization that even imperfect information is useful for policy decision justifies the efforts of investigating pressing issues even without the real chance of robust evidence. The information that such research provides should meet the most stringent criteria, but it should respect the necessity of making a policy decision. So even though some fields in economics have not yet followed the general trend of adding robust, even if small pieces of evidence rather than grand but likely faulty theories, they should nonetheless be further investigated with the goal of providing information for policy makers.

Chapter 2

Heterogeneity of Returns to Business R&D: What Makes a Difference?

2.1 Introduction

Research and development (R&D) is a driving factor for economic development. Not only do firms increase their own productivity through R&D investment (Hall *et al.* 2013), but R&D spending also affects other firms through spillovers (Chen *et al.* 2013). Because of these spillover effects on other firms, privately funded business R&D tends to be suboptimal from the societal perspective. One of the purposes of public support for business R&D is thus to compensate insufficient private R&D spending (Gil-Moltó *et al.* 2011). For a comprehensive view of business R&D deliverables, it is therefore necessary to consider returns to both private and public R&D as well as direct and spillover effects of R&D (Eberhardt *et al.* 2013).

Direct returns to R&D have been estimated several times since the first landmark study by Griliches (1979). A firm's knowledge stock has repeatedly been shown to be positively associated with its productivity (Ortega-Argilés *et al.* 2010). With the suspicion that direct R&D returns of this kind might only represent a fraction of the total returns to R&D, however, research turned to technology spillover showing that they are also important (e.g., Bloom et al., 2013). Technology spillovers depend not only on the investor but also on the recipient's ability to receive the existing knowledge. For instance, R&D spending enhances absorptive capacity, which stimulates catching-up with the technology frontier (Griffith *et al.* 2004). It is important to keep this in mind when analyzing returns to R&D in less developed economies as the less developed economies often lack the prerequisites for successful technology adoption.

Because private and public funding for business R&D spending are differently motivated, the nature of their effects is also likely to vary. Surprisingly, however, the existing studies have largely focused on either private or public returns to R&D and have only rarely considered both. The main exception is Furman *et al.* (2006), who focus on spillovers and distinguish between public and private R&D effects. Acosta *et al.* (2015) link public R&D support to greater labour productivity but do not compare any equivalent effect from private R&D expenditures. More attention has been devoted to the effects of public R&D support on private R&D spending; most of the studies on this topic have found that public R&D support stimulates private R&D spending rather than crowding it out (Becker 2015).

The difference between private and public funding is, of course, not the only source of heterogeneity in the returns to business R&D; demand-driven and supply-driven spillovers, for example, must also be considered as distinct technology diffusion channels. It is customary to focus only on spillovers in the downstream direction (Cheng & Nault, 2007; Wilson, 2001) or to use proximity measures that fail to distinguish the kind of linkages (Lucking *et al.* 2018). Wolff & Ishaq Nadiri (1993), Forni & Paba (2002) and Plunket (2009) consider both directions separately, but not in the context of public and private R&D. Finally, the effects of R&D investment are likely to be non-linear (de Meyer & Mizushima 1989) and fluctuate along the economic cycle (Hud & Hussinger 2015), yet their fluctuation has hardly investigated in the literature.

Our aim in this study is to address the heterogeneity of returns to R&D using a single dataset and provide a novel evidence about R&D landscape in the Czech Republic. For this purpose we carry out an econometric investigation based on panel data from Czechia at the detailed sectoral level for the period 1995-2015. The results indicate that the direct returns to privately funded R&D are positive and statistically significant at conventional levels but the returns to publicly funded R&D are neither positive nor statistically significant. That is not to say that public support for business R&D has no effect, however: both privately and publicly funded R&D investments create positive spillovers. Splitting those R&D spillovers along the upstream/downstream distinction shows that although the downstream course is dominant, some benefits are felt in the upstream direction. The results also suggest that private

R&D only offers significant returns after reaching a critical mass, whereas we do not see this non-linearity in the effects of the public component. Finally, the returns to privately funded R&D were considerably larger after the great financial crisis of 2008, while the returns to publicly funded R&D support decreased. Meanwhile, the spillovers from both types of investment remained unaffected by the crisis.

These results are of particular importance for latecomer economies that are rapidly catching up with the technology frontier through business R&D expenditures, and for which evidence of returns to R&D is scant, as the existing literature has predominantly focused on developed countries. The Czech economy provides fertile ground for studying these effects. Czechia increased its business R&D expenditures as a fraction of GDP from 0.62% in 1995 to 1.13% in 2017, ending up on par with the Netherlands and the UK and overtaking Spain, Portugal, and Italy. The Czech government supported business R&D to the fourth largest extent in the EU between 1995 and 2015 (Eurostat 2019). Nevertheless, analysis of this spending has so far been limited to two studies by Klímová *et al.* (2020) and Sidorkin & Srholec (2017), both of which focus on the additionality effects of both public subsidies and private R&D spending.

The rest of this paper is structured in the following way: section 2 introduces the theory, explains the key concepts and reviews papers relevant to this study; section 3 presents the data and methods; section 4 interprets the empirical results and section 5 concludes.

2.2 Theory and Conceptual Framework

Griliches (1979) produced a pioneering analysis of R&D returns using the production function. He introduced R&D capital stock as an additional input in the production function, which made it possible to estimate the effects of R&D on output. This approach has since been used extensively in the literature on this topic.[1] Moreover, it has drawn attention to R&D spending as an engine of economic progress. In an age of decelerating productivity, public support for R&D is a prominent part of discussions about economic policy (European Commission, 2010).

Policymakers are, or should be, interested in the efficiency of public R&D support. In theory, such support is justified: firms invest in R&D with the

[1] For a review of the empirical literature, see McMorrow & Röger (2009).

vision of raising their future profits, but because those profits can be highly uncertain and the benefits of R&D are often not easy to internalize, private R&D investment could be seen to be suboptimal from the societal perspective. Government R&D subsidies and public research programmes are thus designed to compensate firms for the benefits that their R&D provides to other firms and to facilitate research with high social returns where there is no profitable business model.

In practice, state incentives for R&D either take the form of direct subsidies or involve indirect tax deductions for R&D spending. Whereas tax incentives usually cover all sectors engaging in R&D equally, direct subsidies address specific industries and technologies, so the government can then steer its support to projects with the highest social returns, including spillovers. Whether this is done successfully is a different matter. In his review of R&D and productivity growth, Sveikauskas (2007) concludes that only privately financed R&D offers high returns and that publicly financed R&D yields only indirect effects. Coccia (2010) finds that public R&D spending complements private spending only if the former does not exceed the latter. Public R&D support does not seem to crowd out private investment (Czarnitzki & Lopes-Bento 2013), and there is even some evidence that public R&D support can boost privately funded R&D (Guellec & Van Pottelsberghe De La Potterie 2003). A review of crowding-out and additionality effects is nonetheless inconclusive (Becker 2015; David *et al.* 2000; Zúñiga Vicente *et al.* 2014).

The standard variable used to capture spillovers in the relevant research is the weighted sum of all R&D capital stocks, where the weights reflect the relative proximity between the subjects of interest (Hall *et al.* 2010). One way of estimating the closeness between countries, industries or firms is to follow Jaffe (1986) and calculate an uncentered correlation matrix of R&D stocks (Bloom *et al.* 2013). For the purposes of industry analysis, however, trade-based weights that consider trade as a spillover vehicle are more appropriate. Coe & Helpman (1995) used import shares, assuming that close trade relations lead to technology and knowledge diffusion opportunities. In this study, we follow Meda & Piga (2014) in using an input-output structure to estimate the connectedness of the industries.

Based on the input-output matrix, we can calculate both forward and backward trade linkages. This enables us to distinguish between the directions of the technology spillovers. Wolff & Ishaq Nadiri (1993) consider spillovers in both directions, but they find only the forward direction significant. Forward linkage is usually the only spillover direction considered, since it is assumed that better inputs will increase product quality or process efficiency. Backward spillovers are largely neglected in the literature, with just a few exceptions (Forni & Paba 2002; Plunket 2009). Yet the customer's technological progress may also drive suppliers to innovate, and this is especially likely in tightly knitted value chains where central firms with many sub-suppliers define the production process (Gereffi *et al.* 2005).

Distinguishing between forward and backward spillovers helps us to differentiate between technology and rent spillovers (Mohnen 1997). Griliches (1979) makes a distinction between rent spillovers and pure knowledge spillovers. Rent spillover affect predominantly the downstream industries which benefit through qualitative improvements in their inputs. It is not immediately clear why the private R&D expenditures would not be reflected in the prices, however. If R&D leads to technological improvement, there is no reason for its costs to be born only by the respective firm. Even if the prices reflect R&D costs though, the stochastic nature of R&D efforts means the the qualitative improvements do not occur gradually. There are therefore swings in product quality not reflected in prices which are the rent spillovers.

In case of public R&D support the discussion of prices reflecting R&D costs becomes obsolete. Since the costs are not born by the respective firms, any qualitative improvement of the intermediate product is a rent spillover for the downstream firms. While estimating knowledge spillovers happening down the stream, they are likely positively biased. Without that bias, forward R&D spillovers may even be negative. Indeed, Dietzenbacher & Los (2002) state that R&D costs are reflected in output prices, which negatively affects downstream industries. They further show that backward and forward linkages are heterogeneous, which means that using them as weights yields independent measures of shared R&D capital and this dispels fears of collinearity in the estimation.

Forward and backward spillovers may play a special role when it comes to public R&D support. Direct public support is essentially a fiscal stimulus and so, even with no technology gains, it can have a positive effect on the receiving sector. Moreover, such a positive effect could spill upstream to other industries via increased demand. Thus, if we measure knowledge spillovers based on the suppliers' shared knowledge pool, this may produce an overestimation. However, there is little reason to assume that the simple fiscal effect trickles down and benefits downstream industries to any large extent, hence the bias in the latter direction should be small.

Estimations of R&D returns for whole economies often allow no space for heterogeneity, although there are some exceptions. Based on the rationale of Cohen & Levinthal (1990), Griffith *et al.* (2004) find that industries with lower R&D intensity profess faster productivity growth than the technology forerunners and that technology transfer can be further induced by the receiver's absorptive capacity. Braconier & Sjöholm (1998) provide a comprehensive study on both inter and intra-industry spillovers, showing that both exist. The heterogeneity of R&D effects could also depend on the level of R&D spending itself. Low levels of R&D investment may only have a minuscule effect and substantial returns might materialize only after a critical mass of R&D capital is achieved (de Meyer & Mizushima 1989).

Another strand of literature has explored the distinction between private and public R&D spending in the estimation of their interplay with productivity. Segerstrom (2000) provides a theoretical framework for the long-term effects of public R&D spending, but with little empirical evidence. Haskel & Wallis (2013) show that public R&D spending (specifically on research councils) spills over to market sector productivity. Other papers have focused rather on direct impacts on firm behaviour (Busom 2000). Firm-level studies are perfectly fit for the matching approach in the analysis (Almus & Czarnitzki 2003), but this technique neglects the magnitude of the public - which is crucial for policy evaluation - as it only uses a binary distinction between treated and not treated.

Microdata are suitable for estimating direct effects from R&D as they provide great detail and statistical power, but they are less fit for evaluating spillovers. Despite the fact that R&D spillovers happen between firms at the micro-level, it is not clear how to assess the degree to which firms interact with one another. Spillovers are thus generally neglected in evaluation studies based on microdata (Baumann & Kritikos 2016). Industry-level data, on the other hand, provide the opportunity to relate one industry to another through input-output tables and, based on this measure, to estimate the indirect spillover effects of R&D spending. The downside of using this approach is that intra-industry spillovers are neglected, but it can still provide some useful insights.

2.3 Data and Model

The Czech Statistical Office (CZSO) conducts an annual survey on R&D, covering all firms that CZSO believes to have R&D activities. The data on R&D

spending can be split according to the source of financing - private or public - and the nature of the expenditure - current or investment. The survey's response rate oscillated around 84 percent over the years 1995-2015, which is high in international comparison. Nevertheless, some data was still missing due to non-response.[2]

CZSO provides data on value-added, labor, and capital at the detailed NACE 120 level.[3] The R&D data has been aggregated to match this classification. Because many of the NACE 120 industries are barely engaged in R&D, we focus on 61 manufacturing and selected service industries, for which the R&D statistics are reliable.[4] This subset of industries accounts for more than 90 percent of all R&D spending. An overview of the sectors included in the analysis is provided in Appendix A1. Only data from private companies are used in the analysis, so that we analyze only business R&D returns and spillovers; we do not mix research at public universities and public research institutions into our analysis. All the monetary variables are transformed into 2010 prices in CZK using sector-specific deflators.

The timing of R&D effects is difficult to pin down (Hall *et al.* 2010). To deal with this problem, we construct a measure of R&D capital stock for each sector. Using stock instead of flow variables enables us to relate past R&D expenditures to current productivity. Hence:

$$R_t = (1 - \delta)R_{t-1} + r_t \tag{2.1}$$

where R_t is the R&D capital stock at time t, r_t is the R&D expenditure at time t, and δ is the depreciation rate. The depreciation rate is a parameter set to 15%, which is standard in this literature (Hall *et al.* 2010) but note that its value does not affect the estimates in any significant way. After logarithmic

[2]We can never be sure whether a missing observation is a non-response or whether the firm ceased its R&D activity. Extrapolation of the missing data is not feasible, because some firms might have ceased operations during the covered period, but it is possible to interpolate the missing data within a time series, because R&D expenditures do not drop to zero for just a few years, especially in large firms. We thus interpolate data on firms with more the 250 employees if the gap between their observations is no more than three years.

[3]NACE 120 is a combination of NACE two-digit and three-digit numerical distribution (i.e. divisions and groups).

[4]We used the Mahalanobis outlier detection procedure to identify outliers. Using critical values even more conservative than those suggested by Penny (1996) implicated the manufacture of coke and refined petroleum products, mainly because of a highly unstable price index. We have therefore excluded this manufacturing industry from our analysis (as did Eberhardt *et al.* (2013).

transformation, the rate becomes a constant that only affects the fixed effects estimation to a limited extent.[5]

For our iterative approach we need to determine the level of R&D capital at time 1. Following Hall *et al.* (2010), we assume that R&D expenditures have a constant growth rate (which is supported by the empirics) and constant depreciation rate:

$$R_2 = \frac{r_1}{g + \delta} \tag{2.2}$$

The estimation dataset covers the years 1996-2015. The flexibility of the R&D capital stock model, however, enables us to differentiate between publicly and privately funded R&D stocks in the analysis. A share of the R&D stock constructed in this way consists of capital stock. We cannot distinguish in the data between a computer purchased for a researcher or one for a reception desk. This leads to double-counting which can be a source of bias in our estimation of R&D returns. Fortunately, the data contains information on how much R&D spending is of an investment character, so if we assume that investment-related R&D stock is proportional to R&D investment, it is then possible to calculate the precise share of R&D stock that is also included as capital stock. We can then subtract this from the ordinary capital stock to avoid double-counting.

To evaluate the spillovers of R&D spending we construct an auxiliary variable, shared R&D stock, which weights the R&D stock in other sectors depending on their connectedness. We follow a suggestion from Eberhardt *et al.* (2013) and construct the weights based on the input-output structure of the economy. The knowledge flow can flow either from supplier to customer (forward) or the other way around (backward). We thus differentiate between these two directions of knowledge stock sharing, using weights based on supplier or customer input-output linkages. Input-output tables provided by CZSO are used. They

[5] The choice of depreciation rate affects the estimation but only in a mild and predictable manner. First, as it is apparent from equation 2.2, the choice of depreciation rate influences the value of imputed R&D stock. The magnitude of this effect is not trivial as it depends on the value of g. However, the effect logically wanes over time. Moreover, it wanes at a predictable rate (the depreciation rate), so the log-log transformation with fixed effects controls for that in the estimation.

Second, the different depreciation rate affects the level of R&D stock at each point in time. However, the effect is the same at each point in time, so the log-log transformation along with the employment of fixed effects again controls for the different values of the depreciation rate.

The choice of the depreciation rate indeed affects the estimation, but only through the value of the first observation.

cover 81 industries mirroring NACE2, so their mapping to the granularity of the remaining data is possible.

Consider the forward-shared R&D stock at the industry $i's$ disposal that stems from industry j. We take the value of $j's$ supply to i and divide it by the overall input of industry i. By repeating this step for all the industries that supply industry i, we obtain a set of weights, by which we then multiply the respective R&D stocks. The sum is the total forward-shared R&D stock. Backward-shared knowledge stock is calculated similarly. Equation 3 shows the calculation of forward-shared R&D stock with a_{ij} being the element of an input-output matrix in the ith row and jth column.

$$forward\,shared\,R\&D\,capital\,stock = \sum_{j \neq i} w_j^j R_j,\ where\, w_j^j = \frac{a_{ij}}{\sum_j a_{aj}} \tag{2.3}$$

Table 2.1 presents the summary statistics. The effective unbalanced panel consists of 930 observations from 61 industries over 19 years. There is strong heterogeneity between sectors and over time. Private R&D spending dwarfs public spending by a ratio of four to one, while the levels of forward-shared and backward-shared capital are comparable. Some smaller industries have no R&D spending in a particular year, but these do not drive the results - the results remain similar even when we omit these. Public and private R&D capital are correlated but not to such a degree that this would cause multicollinearity issues. While manufacturing is generally more R&D intense than services, public R&D support is greater, as a share of total R&D capital, in the service sector.

To relate R&D spending to value added, we use the Cobb-Douglas production function augmented with R&D stock as the baseline model for our analysis. We follow the notation presented by Hall *et al.* (2010) and the canonical approach of Griliches (1979):

$$Y = AL^{\beta_1} C^{\beta_2} K^{\beta_3} [K^S]^{\beta_4} e^u \tag{2.4}$$

where Y is value-added, A is the shared level of technology, L is labour input, C is capital input, K is $R\&D$ stock, and K^S is the shared knowledge pool. The coefficients β_3 and β_4 measure elasticities with respect to internal R&D stock and shared R&D stock. Taking the logarithmic transformation of the equation above, we obtain a linear model with elasticities as coefficients.

Table 2.1: Summary Statistics

930 observations	MEAN	SD	MIN	MAX
Value added	9,976	13,524	5	113,617
Fixed capital stock	32,377	75,079	76	836,300
Labour (FTE)	20,826	25,128	86	152,388
Private R&D expenditures	124	270	0	2,440
Public R&D expenditures	28	85	0	963
Private R&D capital	648	1,342	1	9,703
Public R&D capital	138	409	1	3,898
Private forward-shared R&D capital	514	379	32	2,278
Public forward-shared R&D capital	79	73	1	394
Private backward-shared R&D capital	423	448	21	4,354
Public backward-shared R&D capital	58	48	1	219

**All variables (except labor) are in CZK million.*
***Labour is in full time equivalent units.*

Lowercase letters represent the variables after the logarithmic transformation. It is further assumed that the trend in technological development can be described by time effect λ_t and the industry heterogeneity in productivity by the industry effect μ_i.

$$y_{it} = \mu_i + \lambda_t + \beta_1 l_{it} + \beta_2 c_{it} + \beta_3 k_{it} + \beta_4 k^s_{it} + \epsilon_{it} \tag{2.5}$$

We further distinguish between private and public R&D capital and we split the shared capital stock into private/public and backward/forward varieties:

$$\begin{aligned} y_{it} = \mu_i + \lambda_t + \beta_1 l_{it} + \beta_2 c_{it} + \beta_3 private\, k_{it} + \beta_4 public\, k_{it} + \\ \beta_5 private\, k^s_{it} + \beta_6 public\, k^s_{it} + \epsilon_{it} \end{aligned} \tag{2.6}$$

$$\begin{aligned} y_{it} = \mu_i + \lambda_t + \beta_1 l_{it} + \beta_2 c_{it} + \beta_3 private\, k_{it} + \beta_4 public\, k_{it} + \\ \beta_5 forward\, k^s_{it} + \beta_6 backward\, k^s_{it} + \epsilon_{it} \end{aligned} \tag{2.7}$$

There are several issues with this specification. Successful industries with rising value added may increase their R&D spending, but increased R&D spending may also stimulate their value added, thus the results lack causal interpretation - the causal effect of R&D spending is likely smaller than our estimates. However, the upward bias may not be too large. Griffith *et al.* (2004) argue that because productivity is pro-cyclical, but the ratio of value added and R&D

expenditures is not, the bias remains modest even in simple models without identification specification using exogenous shocks.

Moreover, the specification implies that, for instance, the absence or public R&D capital leads to the industry producing nothing. This is unrealistic. A specification grouping the R&D capital stock together and only allowing for distinct efficiencies would be more elegant. A measure of public R&D capital intensity would potentially do the trick. Yet, its incorporation into the production function remains opaque. Since I was not able to come up with a more elegant and rigorous specification than (2.6), this paper sticks with the imperfect specification which, however, provides clearly interpretable results.

2.4 Econometric Estimates

Our models are estimated using fixed effects within a method for panel data, which controls for common time trend and industry-specific effects. The elasticities of R&D capital and shared R&D capital reveal the association between a 1 % increase in the respective stock and any change in value added. Elasticity is not a measure of return. To obtain that, one would have to multiply that by the ratio of value-added and R&D capital stock. Since we are mainly interested in the statistically significant associations between value-added and different kinds of R&D capital stock, we present elasticities in the following regression tables while suggesting positive or negative R&D returns in the interpretation of the results. This approach is sound as long as we do not make any inferences about the magnitude of the results or it is permissible to assume a similar ratio of value added and R&D capital stock in the compared categories.

Although estimating R&D returns and distinguishing between financing sources, recipients and other categories could be difficult due to the collinearity of the key variables, our model does not suffer from these issues: the variance inflation factor reveals that the collinearity of the variables we use is at a permissible level (see the Appendix A.1). All the results are reported with robust standard errors, taking into account heteroscedasticity and cross-sectional correlation.

Table 2.2, column 1 presents the baseline results with aggregate R&D capital and aggregate shared R&D capital and indicates significant direct R&D returns with the elasticity of 0.04. This is in line, for instance, with the past estimates of 0.04 by Bloom *et al.* (2013) and 0.06 by Eberhardt *et al.* (2013).

The indirect spillover term is also highly statistically significant with an estimated elasticity of 0.11, and again this is not substantially different from past estimates: 0.07 by Adams & Jaffe (1996), 0.09 by Wolff & Ishaq Nadiri (1993). Splitting the R&D capital along the private/public axis (column 2) shows that the direct returns are mainly driven by private spending. There is no evidence that public R&D capital has any direct link to sectoral value added. Condemning public R&D support would, however, be premature. After dividing shared R&D capital into public and private capital, it is apparent that public spending is positively associated with value added through spillovers (column 3). Interestingly, the magnitude of these spillover effects is similar for both public and private R&D stock.

Table 2.2: R&D returns and spillovers - benchmark results

Response: valued added	(1)	(2)	(3)	(4)
Fixed capital	0.270***	0.268***	0.306***	0.320***
	(0.068)	(0.069)	(0.052)	(0.051)
Labour	0.835***	0.834***	0.857***	0.857***
	(0.050)	(0.052)	(0.036)	(0.035)
R&D capital	0.040***	-	-	-
	(0.011)	-	-	-
Shared R&D capital,	0.112***	0.120***	-	-
spillover	(0.028)	(0.004)	-	-
Private R&D capital	-	0.020*	0.023**	0.022*
	-	(0.009)	(0.008)	(0.009)
Public R&D capital	-	0.003	0.005	0.005
	-	(0.004)	(0.004)	(0.005)
Private shared R&D capital,	-	-	0.078**	-
spillover	-	-	(0.028)	-
Public shared R&D capital,	-	-	0.118***	-
spillover	-	-	(0.029)	-
Backward-shared R&D capital,	-	-	-	0.039*
spillover	-	-	-	(0.016)
Forward-shared R&D capital,	-	-	-	0.070**
spillover	-	-	-	(0.024)
Adjusted R-squared	0.530	0.530	0.540	0.542
Fixed effects (years)	Yes	Yes	Yes	Yes
Fixed effects (industries)	Yes	Yes	Yes	Yes
Number of observations	930	930	930	930

**** p<0.01, ** p<0.05, * p<0.1*

Dividing the shared R&D capital stock based on forward and backward linkages of the industries (column 4) shows that spillovers happen in both directions. However, spillovers from supplier to consumer seem to be more prominent. This is in line with the notion of rent spillovers more likely to happen in the forward direction. Splitting the spillover term even further, into public/private in both directions would be even more revealing but, unfortunately, collinearity issues make such an estimation unreliable.

Next, we examine non-linearity in R&D returns. We use threshold regression models to inspect potential discontinuity in R&D returns. It is likely that once R&D capital reaches a certain critical mass, its effect changes. Criscuolo *et al.* (2005) uses the example of drug development to highlight the need for large amount of human and financial resources in large-scale research activities. We thus hypothesize that when the investment reaches such a critical mass, returns to R&D capital increase. Following Fong *et al.* (2017), we estimate the change points based on the exact method where the estimated change point is chosen from a grid based on the likelihood of the final estimation. Figure 1 shows the likelihood distribution of the change points in private R&D capital stock. The distribution suggests there is indeed a critical value beyond which the returns to R&D tend to be linear. The procedure of Fong *et al.* (2017) showed that the chosen change point is indeed statistically significant (with p-value of 0.004), but it did not identify a statistically significant change point in public R&D capital stock.

We continue with a segmented threshold regression which estimates a linear relationship between the dependent variable and the threshold variable both below and above the threshold. This is equivalent to the standard estimation if we let the independent variable of interest interact with a dummy which is equal to one when the values of the particular independent variable are greater than the estimated threshold. The interpretation is then analogical to any model with interaction terms.

Table 2.3 below provides threshold regression estimates for both private (columns 1 and 2) and public (columns 3 and 4) returns to R&D capital. The segmented threshold models show that there is a certain critical level of private R&D capital beyond which the returns are substantial. This is in line with the notion of there being a critical mass of R&D capabilities that firms need to generate in order to profit from their R&D activities (de Meyer & Mizushima 1989). Our estimation does not detect any such critical mass in public R&D capital which is in line with the not statistically significant change

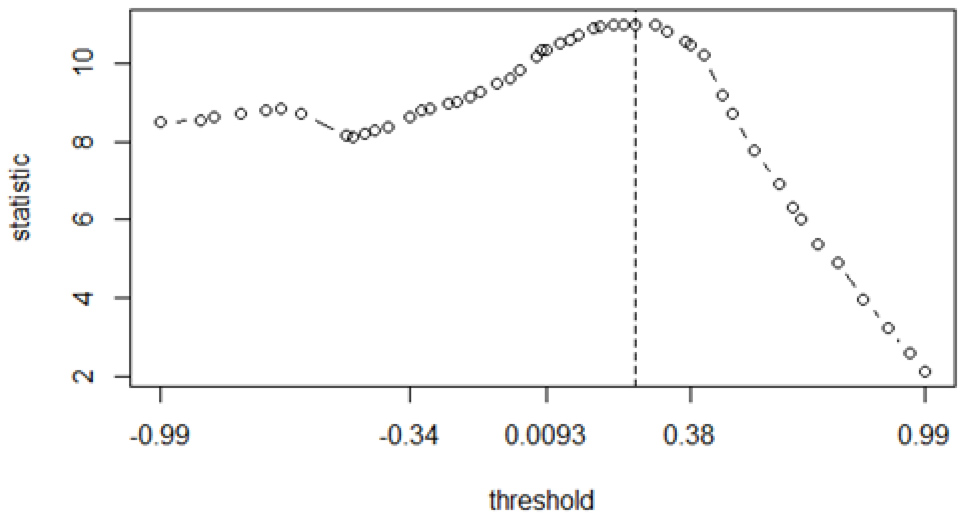

Figure 2.1: Maximum likelihood distribution of change points, private R&D capital stock

point. Distinguishing between public and private shared R&D stock or forward and backward shared R&D stock does not affect the results - we find no evidence of non-linearity in those variables.

It should be noted, however, that the threshold likely varies across industries. Finding a statistically significant single threshold indicates a surprising level of homogeneity of industries in this respect. Not finding a single threshold, on the other hand, does not serve as evidence of linearity of R&D returns. Allowing for industry-specific thresholds in the model specification is unfortunately not feasible because of the number of the observations. It would be advisable with more granular data.

Lucking *et al.* (2018) inspected whether returns to R&D remain stable in time and found that they hardly changed between 1985 and 2015. Their approach was to let the variables interact with dummies reflecting 5-year periods, so as to inspect the general development of R&D returns in time. We are interested in a more specific time question: whether the returns were affected by the great financial crisis. We therefore interact our measures of R&D capital with a dummy capturing the period from 2009 onward, as the crisis hit the Czech economy in 2009.

Table 2.4 provides the results. As the crisis hit, firms were likely tempted to curb private R&D investment in response to their falling revenue. The results indicate, however, that those who managed to maintain their R&D spending benefited handsomely as it extended their lead over their competitors (column

Table 2.3: R&D returns and spillovers - threshold models

Response: valued added	(1)	(2)	(3)	(4)
Fixed capital	0.254***	0.261***	0.270***	0.277***
	(0.070)	(0.071)	(0.070)	(0.071)
Labour	0.841***	0.845***	0.819***	0.822***
	(0.068)	(0.058)	(0.068)	(0.066)
Private R&D capital	0.005	0.001	0.028***	0.028**
	(0.014)	(0.014)	(0.012)	(0.012)
Public R&D capital	0.000	-0.000	-0.013	-0.012
	(0.006)	(0.006)	(0.013)	(0.012)
Private shared R&D capital,	-0.001	-	-0.003	-
spillover	(0.001)	-	(0.003)	-
Public shared R&D capital,	0.049***	-	0.041**	-
spillover	(0.019)	-	(0.019)	-
Backward-shared R&D capital,	-	-0.001	-	-0.003
spillover	-	(0.001)	-	(0.003)
Forward-shared R&D capital,	-	0.061***	-	0.053**
spillover	-	(0.022)	-	(0.023)
Private R&D capital, threshold	0.17***	0.17***	-	-
	(0.05)	(0.05)	-	-
Public R&D capital, threshold	-	-	0.019	0.018
	-	-	(0.045)	(0.044)
Adjusted R-squared	0.530	0.530	0.530	0.530
Fixed effects (years)	Yes	Yes	Yes	Yes
Fixed effects (industries)	Yes	Yes	Yes	Yes
Number of observations	930	930	930	930

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

1). The returns to private R&D in the years 2009-2015 were more than twice as big as those in 1996-2008.

Table 2.4: R&D returns and spillovers - the effects of the economic crisis

Response: valued added	(1)	(2)
Fixed capital	0.306***	0.306***
	(0.052)	(0.053)
Labour	0.875***	0.881***
	(0.036)	(0.036)
Private R&D capital	0.020**	0.020*
	(0.010)	(0.010)
Public R&D capital	-0.006	0.005
	(0.009)	(0.005)
Private shared R&D capital, spillover	0.032	-
	(0.019)	-
Public shared R&D capital, spillover	0.075***	-
	(0.022)	-
Private R&D capital x	0.043***	0.045***
period (2009-2015)	(0.013)	(0.013)
Public R&D capital x	-0.041***	-0.045***
period (2009-2015)	(0.013)	(0.013)
Private shared R&D capital x	-0.063	-
period (2009-2015)	(0.039)	-
Public shared R&D capital x	0.056	-
period (2009-2015)	(0.031)	-
Backward-shared R&D capital,	-	0.039*
spillover	-	(0.017)
Forward-shared R&D capital,	-	0.075***
spillover	-	(0.025)
Backward-shared R&D capital x	-	0.007
period (2009-2015)	-	(0.020)
Forward-shared R&D capital x	-	-0.078
period (2009-2015)	-	(0.020)
Adjusted R-squared	0.555	0.559
Fixed effects (years)	Yes	Yes
Fixed effects (industries)	Yes	Yes
Number of observations	930	930

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Public R&D spending is not positively associated with sectoral performance during the crisis. This can be explained by R&D support having been used as an immediate fiscal stimulus when the crisis hit. With other tools for government support not yet in place, public R&D spending might have been streamed to the struggling industries in order to keep them afloat. Accordingly, the direct returns to public R&D spending are estimated to be essentially zero in pre-crisis years but turn sharply negative in 2009. This drop in returns to public R&D is in line with Hud & Hussinger (2015), although they did find a small positive effect. The spillovers - divided into public/private (column 1) or forward/backward (column 2) - were not, however, affected by the crisis.

2.5 Conclusion

In this paper, we have analyzed direct and spillover returns to R&D in Czechia. While direct returns only come from private R&D spending, spillover effects are driven by both privately and publicly funded R&D and happen both forwards and backwards in the production process. The great financial crisis increased direct returns to private R&D funding and decreased direct returns to public R&D funding, widening the gap in direct returns.

Our results are mainly explorative: no claim of causality can be made using our specification. Successful industries may invest in R&D with visions of further growth, while struggling industries may rather restrict their R&D investment to improve their cash flow. The cause-effect direction between value added and R&D investment would then be the opposite of that usually suggested. This means that the R&D returns we have presented here are likely overestimated. However, as we have mentioned, this upward bias is likely small (see Griffith *et al.* (2004)). Another source of upward bias in our estimates of direct R&D returns are spillovers between firms within the same industry; these are not considered in our industry analysis and are thus counted as direct returns. While this is a serious matter, it should not be overstated: our results do not differ substantially from those presented in studies that used firm-level data (Hall *et al.* 2010; Rogers 2010). Lastly, it is difficult to distinguish between true knowledge spillovers resulting from public R&D spending and mere rent spillovers. However, by splitting the shared public R&D capital into forward and backward directions, we show that technology spillovers are likely far more substantial than rent spillovers.

Despite these various shortcomings, our results largely confirm the common intuition as to the benefits of R&D spending, with positive and significant direct and spillover R&D returns (with the exception of direct returns to public spending). The absence of a positive direct return to public R&D support shows that intra-industry spillovers - which would also be captured by the direct effect - are indiscernible. Assessments of public R&D support should thus not be limited to institutions' immediate industry partners: the spillover effects of public investment in R&D are likely far-reaching and may materialize in other industries over longer periods of time. [6]

The direct effects of R&D spending are not linear, and this fact should be taken into account in R&D-enhancing policies. More specific research is needed to establish how policies should be adjusted to these phenomena. Ideally, a proper impact assessment involving different groups of stakeholders must be conducted before any policy is implemented. Such assessments should be based both on industry data and microdata. The results presented in this paper are generalizable only at the industry level. Using firm-level data would provide complementary evidence and map the Czech R&D landscape in greater detail. With increasing data availability, such a study will hopefully be possible in the near future. Granular data could help us identify causal effects, show how returns to public R&D differ based on sources of financing (regional, state, EU funds), and uncover synergies in distinct R&D projects.

[6] R&D spillovers are not just a domestic phenomenon. Cross-border spillovers are likely also important for technology transfer as different levels of development across countries provide an opportunity for a flow of new technology from the leader to the laggard. To estimate those flows for Czech industries, R&D intensity of trading partners of each industry would be required. With increasingly detailed and harmonized industry-level statistics, it would be possible to construct such a data set. Suffering from incompleteness due to some missing data, it could nonetheless serve as additional input for the formulation of industrial policy.

Chapter 3

Who Benefits from Global Value Chain Participation? Does Functional Specialization Matter?

3.1 Introduction

Global value chains (GVC) have integrated economies into global and complex production chains that offer new opportunities for upgrading (Kummritz *et al.* 2017). Knowledge spillovers and network effects have been shown to positively influence productivity (Frohm & Gunnella 2017). However, GVC participation does not distribute its gains evenly across the board, even though the value-added of the chain as a whole rise (Gereffi & Fernandez-Stark 2016).

The past few decades have been marked by the integration of developing countries into the world economy at an unprecedented pace (World Bank, 2016) and this phenomenon raises questions about the heterogeneity of GVC participation. Kummritz (2015) showed that the effects of GVC participation are different for low and high-wage countries, with the latter benefiting more. Fagerberg *et al.* (2018) confirmed that countries with low capabilities appear to be particularly disadvantaged in this regard. These insights are not only relevant for developing countries: differences in technological development are also present among industries in the developed world.

This paper contributes to this line of research by exploring the heterogeneity of GVC effects in a novel and more detailed way. It joins the insights of empirical research of GVC (Kummritz 2015) and functional specialization (Timmer *et al.* 2019) and attempts to put those in the context of the GVC hierarchy

(Gereffi *et al.* 2005). Additionally, it increases the granularity of the metrics for GVC participation and introduces the measures of GVC participation based on the functional specialization of the partner industry.

Using proxies for GVC participation and functional specialization, based on data from the World Input-Output Database (WIOD) and function specialization data collected by Timmer *et al.* (2019) on 35 industries in 40 countries during the period 2000-2011, we show that the benefits of GVC participation depend on the participants' functional specialization as well as the functional specialization of their GVC partners. Our results indicate that fabrication-focused industries profit from GVC participation more than industries specialized in other business functions and that this is largely because of their engagement with R&D-oriented GVC partners. Grouping countries according to their levels of economic development shows that GVC participation with R&D-oriented industries benefits low-developed countries the most and that fabrication-related GVC participation benefits those countries the least.

We aim to bridge two strands of literature regarding GVCs: rather qualitative papers with strong foundations in management theory (e.g. Gereffi *et al.* (2005); Ernst & Kim (2002)) and empirical, exploratory works which make us of newly available data such as WIOD or firm-level data (e.g. Stöllinger (2021); Timmer *et al.* (2019); Baldwin *et al.* (2014)). These two strands have, to our belief, developed mostly independently, to the detriment of understanding the consequences GVCs have on distinct actors of the world economy.

Although we are careful not to make any inferences about causality, this paper's results reveal where the benefits[1] of GVC participation tend to be concentrated. These results call for a more nuanced view of the potential benefits of GVC participation and highlight the fact that latecomers to GVCs are in a significantly different position from those who run the show. National governments, as well as major international organizations, should take note that GVC participation effects are not uniform across all countries and industries and that they depend on the structure of the particular GVC. Some development policies should be adjusted in light of these findings. The bottom line is functional specialization makes a difference in where the benefits of deepening globalization are felt.

[1]The benefits are measured by production function and are usually referred to as the effects on value-added as it is custom in the related literature. Another possibility would be to refer to the effects on productivity. This would not be false but because we want to describe also value-added resulting from GVC hierarchy, value-added effects seem more appropriate.

The rest of the paper is structured as follows: section 2 introduces the theory and explains the key concepts; section 3 describes the data and methods; section 4 presents the empirical results and section 5 concludes.

3.2 Theory, concepts, and hypotheses

Trade theories were long focused primarily on trade in final goods, with the market the only exchange platform considered. With rapidly decreasing transaction and communication costs driven by advancing technology, however, more elaborate structures that are very different from the simple exporter-importer relation have proliferated. Production has increasingly been sliced into individual tasks which come together to make up a final product. The concept of trade in final goods has thus given way to the idea of trade in tasks (Grossman & Rossi-Hansberg 2008). Trading tasks requires a greater degree of coordination, and so hierarchical models other than purely market-based models were adopted (Gereffi *et al.* 2005). GVC analysis focuses specifically on how the production process is sliced up and on the non-market interactions that this division produces.

This does not mean that classic trade theories are irrelevant. Countries do still exchange goods based on their relative competitive advantage (Ricardo, 1817), and they specialize in production intensive in their abundant factor (Heckscher 1919; Ohlin 1935). GVCs, like trade, are shaped by geographical and cultural proximity: firms naturally seek interactions with low transaction costs, both in terms of transportation and communication (Ernst, 2002). This long resulted in a rather limited set of potential trading partners. However, as advances in technology and the removal of legal obstacles decrease transaction costs, new trade opportunities arise all over the world (Müller & Seuring 2007).

Analyzing GVCs rather than just trade gives us the opportunity to study the non-market relations between participants. The benefits of GVC participation are - with the exception of economic gains caused by knowledge transfer, spillovers, and specialization - driven by participants' positions within the hierarchy of the GVC (Kaplinsky 2000). It well might be that those GVC participants who occupy prominent positions in the GVC hierarchy in terms of their tasks and specialization within the GVC benefit more from the GVC than the rest. That is what we are interested in exploring in this paper.

3.2.1 Heterogeneity in the effects of GVC participation

Engaging firms with distinct capabilities in a GVC does not benefit all the firms in that GVC equally. The logic of technology gains suggests that firms with fewer capabilities will benefit the most from inter-firm cooperation (Blalock & Gertler 2009), but this narrative misses a crucial reality. Firms with rare capabilities that offshore or outsource routine production tasks to other firms experience gains that cannot be explained in terms of technology improvements (Lee & Gereffi 2015). This is made possible due to the uneven distribution of value-added across the production process, described by the smiling curve. The firms that dominate a particular GVC can influence its architecture and position themselves in the GVC stages associated with the greatest value-added, as they essentially govern the GVC. Consequently, firms with fewer capabilities are left responsible for tasks that are linked with very little value-added.

Possessing demanded and rare capabilities is not only beneficial because the market rewards it. Capability disparity within a GVC defines its hierarchy and the value-added distribution. Gereffi *et al.* (2005) identify five forms of GVC governance that largely depend on the capability disparity between the participating firms. When the disparity is high, companies form rigid hierarchical structures and shift a portion of their inter-firm interactions outside the market. When there is no capability disparity and there is no need for explicit coordination, GVCs are governed by the market. GVC participation thus does not only lead to technology transfer and specialization opportunities, but it also determines how much a firm can profit thanks to its hierarchical standing relative to its GVC partners.[2]

Relative capabilities can be observed even at the country or industry level using functional specialization. Using FDI data, Stöllinger (2019) shows that different countries focus on different business functions with richer countries like Germany and the UK focused on R&D and logistics and relatively poorer countries like Slovakia and Poland being active mainly in fabrication. Looking at industry-level data, Meng et al. (2020) reveal a similar pattern: industries far and close to the customer get a greater share of the final price than those in the middle. Another take is to measure upstreamness (Antràs *et al.* 2012), i.e., the distance from the final customer, and relate this measure to economic performance. Descriptive analysis of Hagemejer & Ghodsi (2017) shows that

[2]Dominant firms have many opportunities to exert power within their GVC. One example is management of working capital: the dominant link in the GVC can force others to accept their preferred payment calendars (Kaplinsky 2000).

despite the convergence of the new EU member states, they remained surprisingly upstream - they merely focused more on intermediate products. The relationship between this structural change and value-added, however, remains opaque.

Such value-added distribution along the stages of production is very similar to the "smile curve" we observe at the firm level. The lesson from firm-level data is thus transferable to the whole economy with a strong implication of functional specialization. Functional specialization and specialization in production stages are two distinct concepts, yet they often used interchangeably when moving from the firm (Rungi & Del Prete 2018) to the economy-wide perspective (e.g. Mudambi (2008). Stöllinger (2021) shows that the shape of the economy-wide smile curve is indeed similar to the firm-level curve, and Baldwin *et al.* (2014) provide evidence that it has become even curvier in recent years, with the service sector gradually increasing its value-added share at the expense of manufacturing. The assumption made in this paper is that R&D business functions come as one of the first stages of production, whereas the marketing business function comes as the last. At the macro-level, it thus makes little difference whether we refer to functional specialization or specialization in production. What matters is the rare capabilities contained in those functions which define the hierarchy of the value chain and its value-added distribution.

To increase one's value-added, one can either improve the productivity of the current tasks or move to the part of the value chain with greater value-added. Humphrey & Schmitz (2002) call these two channels process upgrading and functional upgrading, respectively. Competent GVC partners can serve as sources of new technology improving efficiency. Ernst & Kim (2002) posit that GVCs can serve as a knowledge conduit between heterogeneous firms, both through the market (FDI, trade, and machinery) or through informal channels (technical standards, imitation). Saia *et al.* (2015) empirically support this claim by showing that international connectedness ensures contact with the global technology frontier and such contact positively influences the productivity of all engaged agents.

Process upgrading leads to capability formation (Ernst & Kim 2002), so a firm can acquire capabilities in stages with little value-added and use them for subsequent functional upgrading. But functional upgrading is more difficult and is likely to meet with resistance from other players in the GVC as they protect their market share (Lee & Gereffi 2015). This is of special importance for developing economies. Fagerberg *et al.* (2018), for example, find no evidence of GVC participation being linked to better economic performance, and on the contrary show that countries with underdeveloped capabilities may even suffer from GVC participation. It is possible that the technology gains GVC participation facilitates can be offset by unfavorable positioning within the GVC hierarchy.

This paper investigates the association between value-added, functional specialization, and GVC participation. It is beyond its scope to discern functional upgrading as its dynamic nature is difficult to capture, but we hope to find evidence for process upgrading being related to a certain kind of GVC participation. Fabrication, more than any other specialization, requires GVC participation to be productive, as manufacturing value chains became increasingly complex, interconnected, and global over the last decades (Timmer *et al.* 2014). Moreover, fabrication is often the first step of low and middle-income countries engaging with GVCs. For an industry focusing on fabrication, staying out of the realm of GVCs, either up or down the value chain without access to relevant foreign suppliers or customers, respectively, is not likely to be a viable winning strategy anymore. Process upgrading is largely facilitated by a dominant GVC player in traditional industries focusing on fabrication (Pietrobelli & Rabellotti 2004). Moreover, GVC participation is expected to induce process upgrading mainly through knowledge transfer. Knowledge, in turn, is transferable the easiest in a codifiable form (Hall 2006). As the proportion of codifiable to tacit knowledge is the greatest in fabrication as opposed to other business functions, such as marketing, fabrication-oriented industries are likely better suited to benefit[3] from GVC participation.

The global production networks exploit the ex-ante prospects of the respective comparative advantages, but once they are in place, new opportunities arise from the very structure of the networks. Not only is the existing technology diffused along supply chains (MacDuffie & Helper, 1997), but new systems are also used specifically for developing new technologies and disseminating them immediately within the network (Dyer & Nobeoka, 2000). The perspective of the fabrication-oriented industry is then enriched by distinguishing with what sort of other industries GVC participation happens. GVC participation leads to knowledge spillovers but that is likely to happen only across certain kinds of business functions such as R&D. Although the technological gap could be

[3]Benefit for and industry would be measured as greater value-added given constant inputs of capital and labor.

present across all the business functions, R&D (especially in case of fabrication) is likely easier to be transferred than sophisticated managerial structures. Not all R&D output is codifiable and transferable but the proportion is likely greater than for management business function.

It is not clear whether the power architecture follows the division between developed and developing countries. Horner & Nadvi (2018) claim that the notion of firms from the developed world dully outsourcing and offshoring their low-value-added activities to developing countries is outdated. GVC participation within the global South is on the rise and so are the capabilities of the engaged participants. Taking this argument to the extreme, we should observe the same effects from GVC participation no matter whether we look at GVC participation within the developed world, the developing world, or across the globe. What matters is only the specialization within the chain. Any remaining heterogeneity can be attributed to factors such as favorable path dependency, institutional quality, and human capital (Zhou 2018).

GVCs are traditionally thought of as covering most of the production process, from design and extraction of raw materials to sales and marketing. Such GVCs are structurally different from those that are within a single industry. For instance, collaboration between firms in the automotive industry requires greater cooperation than collaboration between the mining and smelting industries. Shorter, single-industry GVCs have proliferated in the past few decades as production has become more fragmented (Wakasugi 2007).

As a result, we investigate whether GVC participation within a single industry has a distinct effect. Technological proximity offers greater opportunities for technology spillovers, but the need for intense coordination may result in tight hierarchical structures (Gereffi *et al.* 2005). The effects of technology spillovers and GVC hierarchy in intra-industry GVCs are intensified by foreign direct investment, which is particularly common within industry and is also associated with gains in value-added (Liu *et al.* 2000). Controlling for functional specialization, intra-industry GVCs thus should provide more benefits than inter-industry ones.

3.2.2 Empirical approaches to GVC analysis

The empirical research on GVCs has gained prominence in the last two decades. It builds on international trade statistics, customs statistics, and input-output tables (Amador & Cabral 2016). The input-output approach we follow in this study was pioneered by Feenstra & Hanson (1996; 1999) who introduced a measure of foreign share in domestic production and so turned their attention to the global integration of production networks. Hummels *et al.* (2001) took this even further with their concept of vertical specialization, which describes production located in at least two countries and goods crossing borders at least twice.

As novel and useful as this approach was, it neglected possible discrepancies in value-added at each stage of production and circular aspects of production. A new value-added approach by Johnson & Noguera (2012), building on Hummels *et al.* (2001), accounted for the possibility of exporting intermediate goods that are later part of imported final goods by introducing the value-added share of gross exports. This improved estimates of bilateral trade quite significantly. The method was later formalized by Koopman *et al.* (2014) so that gross exports can be easily broken down into value-added flows by matrix formulation.

Los *et al.* (2015) introduced yet another metric to measure international fragmentation. Building on Feenstra & Hanson (1999), they present the foreign value-added share, which accounts for the inter-industry circular flow of goods and avoids double-counting, similarly to Johnson & Noguera (2012). This measure enables researchers to investigate GVC participation within a single country or region or indeed on a global scale. It is thus suitable for detailed GVC analysis, as it can be sliced and diced at will, and has indeed been used extensively in recent empirical papers (see Blanchard *et al.* (2016) or Wolszczak-Derlacz & Parteka (2018). Specifically, Timmer *et al.* (2014) provide a detailed analysis of the development of GVC participation over time and of the way GVC participation affects capital and labor shares. Los *et al.* (2015), building on this work, show that although many GVCs are clustered within regions, the truly global ones have progressed far more than the regional ones.

Notwithstanding the convincing results, the methods used in this strand of research are not clear of criticism. Nomaler & Verspagen (2014) argue that this type of aggregated input-output analysis is significantly distorted. The aggregate nature of the input-output means that intra-industry circular flows are ignored. Take the manufacturing of the electrical equipment industry as an example: undoubtedly, electrical equipment is an input to this industry. This value-added is lost in the aggregation because it happens within the same sector. Also, value-added-to-output ratios, which are used extensively when computing measures such as foreign value-added depend on the GVC stage. The ratios in later stages are smaller as the gross output is greater, which in turn overestimates the contribution to value-added from sectors engaged in the last stages of production.

Another issue is the very nature of the input-output data. Because the original data is the supply and use tables which are infrequent, its longitudinal dimension is obtained using an estimation method (Temurshoev & Timmer 2011). Such a procedure exploits data from National Accounts Statistics and comes up with harmonized, comparable time series. Despite the method's quality, one can still argue that the data are not direct observation which can skew its analysis. Unfortunately, to our knowledge, no remedy exists at the moment.

3.3 Data and methods

Our analysis is based on data from the World Input-Output Database (Timmer *et al.* 2015). Release 2016 provides a panel of 54 industries in 43 countries over the period 2000-2014. We use input-output tables to calculate foreign value-added share measures (FVAS) and socio-economic accounts for value-added, capital, and labor employed. All the currencies are converted to US dollars and use 2010 prices. For the FVAS calculation, we closely follow Los *et al.* (2015). FVAS reveals how much of the total value-added of the particular GVC is produced abroad - a measure of international integration. Based on the input-output tables, it is calculated in the following way:

$$FVAS(c,j) = \frac{\sum_{k \neq j} VA(k)(c,j)}{\sum_k VA(k)(c,j)} \tag{3.1}$$

where VA stands for value-added, c for the country, j for the industry, k for the GVC partner. The value-added created in each industry within each country is given by the vector $\mathbf{g}$:

$$\mathbf{g} = \hat{\mathbf{v}}(\mathbf{I} - \mathbf{A})^{-\mathbf{1}}(\mathbf{Fe}) \tag{3.2}$$

In this equation, $\hat{\mathbf{v}}$ is a matrix with value-added over gross output on its diagonal, $(\mathbf{I} - \mathbf{A})^{-\mathbf{1}}$ is the standard Leontief inverse, $\mathbf{F}$ is the matrix of the final output, and $\mathbf{e}$ is the summation vector. The choice of matrix $\mathbf{F}$ determines which value chain we consider. For each industry-country pair, we thus have a vector of value-added produced in each of the other pairs which adds up to the gross output. In other words, the vector shows the income shares of each industry's final product in all country-industry pairs. Such vectors can then be sliced and diced at will.

We use data on business functions assembled by Timmer *et al.* (2019). The dataset provides information on workers' income shares for fabrication, R&D, marketing, and management. The dataset spans across 35 industries, 40 countries over years 1999-2011. Merging this dataset with WIOD , we can relate functional specialization with GVC participation, specifically FVAS. This enables us to determine the FVAS related to certain business function. For instance, we calculate how much FVAS of each industry comes from fabrication by multiplying the particular FVAS value with the fabrication share in that industry. The equation below shows the calculation of FVAS related to fabrication in country c, industry j, where $FS^{FAB}_{d,j}$ is fabrication functional specialization in country d, industry j, and $VA_{d,j}(c,i)$ is the value-added produced in country d, industry j for the final product of country c, industry i.

$$FAB\,FVAS(c,i) = \frac{\sum_{d \neq c,j} FS^{FAB}_{d,j} VA_{d,j}(c,i)}{\sum_{d,j} VA_{d,j}(c,i)} \tag{3.3}$$

The same procedure is used to calculate FVAS related to R&D and marketing functional specialization. The business functions measure the relative intensities so they all add up to 1. Increasing specialization in R&D is always offset by decreasing specialization in the remaining business functions. We drop management business function[4] because we want the functional specialization to reflect the specialization in production stages as closely as possible. Since management is necessary for every stage of production, it cuts across the relevant categories.[5] Slicing the FVAS in this way provides additional insights into how the heterogeneity of a GVC affects value-added. Table 3.1 below provides the summary statistics of the key variables. The panel is unbalanced because a few industries in a few countries are missing in the dataset. The statistics are computed across time, industry, and country dimensions, i.e., pooling the data.

We base our estimation on the Cobb-Douglas production function where

[4]Dropping management, we rescale the rest income shares so that they add up to one without management.

[5]Management business function includes not only top management but also middle management positions and even shop floor production managers, i.e., professions such as production and operations manager or manager of research and development. In addition, the management business function comprises professions such as legislators and government officials which have been probably difficult to place elsewhere. Hence, this seems to be rather a residual category from the production stages perspective.

Table 3.1: Summary Statistics

	N	MEAN	SD	MIN	MAX
Capital stock (USD millions)	23,023	1,075	7,134	0	183,308
Labor (FTE thousands)	23,023	384	1,336	0	24,966
value-added (USD millions)	23,023	351	1,174	0	21,379
R&D Business Function	23,023	0.181	0.15	0	1
Fabrication Business Function	23,023	0.315	0.253	0	1
Marketing Business Function	23,023	0.341	0.217	0	1
FVAS total	23,023	0.209	0.16	0	0.936
o/w FVAS related to R&D	23,023	0.035	0.03	0	0.27
FVAS related to Fabrication	23,023	0.066	0.061	0	0.37
FVAS related to Marketing	23,023	0.07	0.056	0	0.431

Source: Author's computations

technology (A) is assumed to be a function of foreign value-added share and the relative intra-industry productivity. As such, this specification is similar to Kummritz *et al.* (2017) - we use value-added as the dependent variable because it captures changes in productivity as well as changes in factor utilization as well as gross profits of firms and workers' wages. The aim is to exploratively relate GVC participation and functional specialization to value-added and try to control for the omitted variables by an extensive fixed effects structure. The basis of our estimation lies in the general production function:

$$Y(A, F) = A(FVAS, ...)F(K, L) \tag{3.4}$$

Logarithmic transformation provides the usual regression equation:

$$\begin{aligned} y_{cjt} = A_{cj} + \beta_1 FVAS_c jt + \beta_2 k_{cjt} + \beta_3 l_{cjt} + \beta_4 RND_{cjt} + \\ \beta_4 FAB_{cjt} + \beta_4 MAR_{cjt} + \lambda_t + u_{cjt} \end{aligned} \tag{3.5}$$

where y is the logarithm of value-added, A is a constant describing the level of employed technology (country-industry fixed effects), $FVAS$ is the foreign value-added share, k is a logarithm of nominal capital stock, l is a logarithm of total hours worked, RND, FAB, and MAR are the income shares for the respective business function, and λ represents the common time dummies. The subscripts c, j, t stand for country, industry, and year, respectively.

Adding the three business functions, we aim to investigate the distribution of value-added along the production stages. The empirical literature shows, that the value-added is the lowest in the fabrication stage Rungi & Del Prete (2018). We thus let our measure of GVC participation, FVAS, interact with the fabrication business function. This tells us, whether the distribution curve flattens as the result of GVC participation or whether it curves even more. In other words, the positive interaction would suggest that GVC participation results in process upgrading beneficial to fabrication-oriented industries. The potential omitted variable bias is mitigated by the country-industry and time-fixed effects. Different levels of productivity between the sectors as well as the development and common shocks are accounted for by the dummy structures employed in the estimation.

To investigate whether fabrication-oriented industries benefit disproportionately from GVC integration wiht R&D-focused peers, FVAS is split into that related to fabrication, R&D, and marketing:

$$y_{cjt} = A_{cj} + \beta_1 RND_{cjt} + \beta_2 FAB_{cjt} + \beta_3 MAR_{cjt} + \beta_4 RND\_FVAS_{cjt} + \\ \beta_5 FAB\_FVAS_{cjt} + \beta_6 MAR\_FVAS_{cjt} + \beta_7 k_{cjt} + \beta_8 l_{cjt} + \lambda_t + u_{cjt} \tag{3.6}$$

Once again letting the fabrication business function interact with the now split FVAS shows how different kinds of GVC participation are related to the value-added distribution along the production stages. If the interaction term is positive, it is a piece of evidence for the specific GVC participation helping fabrication-oriented industries in process upgrading, possibly through knowledge transfer. For instance, we would expect that this effect is especially pronounced when participating in GVCs with R&D-oriented partners. To the best of my knowledge, GVC participation effects have not previously been examined in this way.

To investigate whether high-developed countries can reap disproportionate benefits from GVC participation, we split the countries into three groups of low-developed, medium-developed, and high-developed according to their overall level of economic development. The high-developed group consists of Western countries, Japan, Korea, and Taiwan. Countries from Southern Europe and most post-communist countries form the medium-developed group and the remaining countries are included in the low-developed group. This division is based on that of the World Bank (2019), where our low-developed group mirrors the lower and upper middle income groups. We further divide the high income group of the World Bank according to the income per capita so that we can inspect the differences between different levels of development among the high-income countries. For instance, Germany and Poland both belong to the high income group, but their roles in global value chains are indisputably different. See Appendix A1 for detailed composition of the country groups.

Table 3.2: Mean values of GVC participation related to specific business functions, by country development group, weighted by industry value-added

	Low-developed	Medium-developed	High-developed
R&D business function	0.151	0.189	0.206
Fabrication business function	0.344	0.261	0.228
Marketing business function	0.347	0.389	0.411
FVAS total	0.183	0.232	0.209
o/w FVAS related to R&D	0.031	0.042	0.043
FVAS related to fabrication	0.087	0.098	0.080
FVAS related to marketing	0.065	0.092	0.086

Source: Author's computations

Table 3.2 breaks down the summary statistics according to the country groups. R&D and marketing business functions gain importance with rising country development and the opposite is true for fabrication business function. This corresponds with the findings of Stollinger (2019). The average general GVC participation (FVAS) is similar across the country groups but splitting it reveals a pattern. Low-developed countries are less integrated with R&D-oriented and marketing-oriented GVCs. This suggests low-developed countries are mainly active in manufacturing industries as suppliers. Medium-developed countries are even more participating in fabrication-focused GVCs, but this composition shifts over time as Table 3.3 shows. Their participation in R&D and marketing-oriented GVCs is on par with high-developed countries.

FVAS rose over time for all three development groups (Table 3.3). This is consistent with the evidence from Los et al. (2015) and World Bank Group (2017). Only during the great financial crisis did global economic integration experience a drop. The kind of deepening GVC participation was, however, different between the development groups. All country groups increased their GVC participation related to marketing. But whereas low-developed countries raised their fabrication-oriented GVC participation, the remaining groups focused instead on GVC participation related to R&D. This is best vindicated by countries like Czechia which participates heavily in GVCs dominated by German multinationals concentrating on R&D and marketing. R&D-focused GVC participation is likely the source of knowledge spillovers (as will be examined further), but it Is likely the already developed countries which, due to their composition of GVC participation, benefit the most.

The differences between country group business functions also do not stay constant over time. Only the share of fabrication is diminishing roughly evenly across the country groups. R&D business function, on the other hand, is gaining importance solely in medium and high-developed countries. Marketing business function strengthens everywhere, but the increase is most prevalent in low-developed countries. The rising importance of R&D business function in high-developed countries hints at the possibility of knowledge spillovers from those countries to the less-developed ones, especially with the R&D-related GVC participation soaring.

Table 3.3: Change in business functions and GVC participation related to specific business functions in country development groups between 2000 and 2011

	Low-developed	Medium-developed	High-developed
Δ R&D business function	-0.005	0.018	0.028
Δ Fabrication business function	-0.034	-0.051	-0.044
Δ Marketing business function	0.024	0.008	0.004
Δ FVAS total	0.028	0.028	0.035
o/w Δ FVAS related to R&D	0.006	0.010	0.013
Δ FVAS related to Fabrication	0.010	0.004	0.006
Δ FVAS related to Marketing	0.012	0.014	0.016

Source: Author's computations

3.4 Econometric Results

We use the standard approach of demeaning variables using the within transformation. The country-industry fixed effects are thus implicitly present in the model. The variables in interactions are centered, so that the interactions have clearer interpretation. We further add the time effects to control for the common time development and country-industry effects to account for any additional individual effects. In all the regression results we present clustered standard errors. The estimated coefficients thus describe the association of a unit increase in GVC participation with a percentage change in value-added. The different levels of GVC participation are controlled for by fixed effects. Admittedly, this specification does not identify any causal effect of GVC participation on value-added. Growing industries may increasingly participate in GVCs while GVC participation may bring about more value-added. To identify a causal effect, however, we would need an exogenous shock, which is difficult to find in this context. This paper thus offers only an explorative analysis pointing to potential causal links, without directly inferring causality.[6]

3.4.1 GVC participation and value-added

Table 3.4 presents the benchmark results. In column 1, the total FVAS has a positive impact on value-added, irrespective of the trading partner and its functional specialization within the value chain. This is in line with Kordalska *et al.* (2016).[7] Adding functional specialization of the industry using the intensity of R&D, fabrication, and marketing business functions, column 2 hints that the industries focusing on marketing produce relatively less value-added holding the other factors of production constant. This is somewhat surprising considering the industry-level smiling curve. However, as Rehnberg & Ponte (2018) show, the distribution of value-added is, at the industry level, rather of a smirk shape, so the drop in the final production stage becomes somewhat less shocking. The results do not change when both GVC participation and functional specialization are considered (column 3).

As we hypothesize that GVC participation should also link to value-added through functional specialization, we let it interact with the fabrication business function. Results in column 4 show that fabrication specialization is profitable

[6]Using covariates distinct from GVC participation (yet linked to it), such as foreign direct investment, would make these estimates more precise. But merging the WIOD dataset with another dataset would mean losing observations which, we believe, is not feasible as the aim is to cover as many countries and industries as possible to get the utmost precise picture of the interlinkages in the world economy. However, fixed effects partially mitigate the omitted variable bias.

[7]However, Kordalska et al. use foreign value-added as the independent variable, whereas this study uses foreign value-added share. This study is primarily interested in how relative GVC participation affects productivity. Rising overall foreign value-added does not say much about the effects of GVC participation intensity. FVAS, contrarily, captures directly how much of the total value-added is contributed by different foreign partners.

only if it is accompanied by sufficient GVC participation. Isolated manufacturing industries seem to lag behind those who form the fabric of the GVCs.

Table 3.4: Benchmark results

	(1)	(2)	(3)	(4)
Labor	0.57***	0.57***	0.57***	0.56***
	(0.01)	(0.01)	(0.01)	(0.01)
Capital	0.26***	0.25***	0.25***	0.25***
	(0.01)	(0.01)	(0.01)	(0.01)
FVAS	0.55***	-	0.62***	0.56***
	(0.04)	-	(0.04)	(0.05)
R&D business function	-	-0.02	-0.02	-0.02
	-	(0.02)	(0.02)	(0.02)
Fabrication business function	-	0.01	0.00	-0.11*
	-	(0.02)	(0.01)	(0.04)
Marketing business function	-	-0.06**	-0.06***	-0.06***
	-	(0.02)	(0.02)	(0.02)
Fabrication business function	-	-	-	0.16*
x FVAS	-	-	-	(0.06)
Time effects	Yes	Yes	Yes	Yes
Country-industry effects	Yes	Yes	Yes	Yes
Observations	23,023	23,023	23,023	23,023
Adjusted R-squared	0.53	0.52	0.53	0.53

**** p<0.01, ** p<0.05, * p<0.1.*

However, such an approach neglects the FVAS composition. Distinguishing between R&D-related and fabrication-related GVC participation uncovers heterogeneity of the interplay between GVC participation and value-added. The results in column 1 of Table 3.5 show that the perks of GVC participation are non-existent in the case of marketing-related links. An alternative view is that fabrication-related GVC participation provides disproportionate benefits (Rungi & Del Prete 2018) and that R&D-related GVC links stimulate knowledge transfer. Also, it could be a hint for less value-added being associated with tasks such as assembling which precede distribution and marketing as shown by Stöllinger (2021). Indeed, this is often identified as a problem for countries successful at manufacturing, but lacking distribution channels (e.g. suppliers of the German automotive industry).

Further, we would like to see how GVC participation interacts with the fabrication business function. Do fabricated-oriented industries profit from knowledge spillovers if they are exposed to trade partners engaged in R&D? Letting the now split FVAS interact with the fabrication business functions, it is apparent that it is indeed only the R&D-related GVC participation that makes fabrication competitive (column 2). A possible explanation is that the interaction with more advanced trade partners induces knowledge transfer and thus process upgrading. GVC participation with partners focused on other business functions does not interact with the relationship between value-added and the fabrication business function in any discernible way (columns 3 and 4).

The interaction between fabrication and GVC participation may also rely on the grouping of the business functions. As a robustness check, we consider fabrication and headquarter activities (adding R&D, management, and marketing together) to see whether our results hold. Management dilutes the effect of the remaining business functions, but the main conclusions of this paper are robust to this exclusion.

3.4.2 Intra-industry GVCs and functional specialization

To test whether intra-industry GVC participation is more beneficial than the inter-industry kind, we calculate an FVAS measure that only captures GVC participation within the given industry. The results in column 1 of Table 3.6 suggest a strong positive association between intra-industry GVC participation and value-added. The association is stronger than the GVC participation of the inter-industry kind. Interactions with the fabrication business function (column 2) reveal that this difference is even more pronounced for industries not active in fabrication which is in line with our previous results. Surprisingly, this effect is not observed in the case of intra-industry GVC participation (column 3) suggesting that process upgrading in fabrication happens mainly across and not within industries which contradicts a view of gradual improvement by implementing manufacturing standards and best practices within a specific sector. Such results are, however, preliminary because our distinction of intra- and inter-industry GVC participation relies on the granularity of the given data. If inter-industry GVC participation had stronger effects across more related industries, more granular data would yield different results.

3.4.3 Does country development matter?

Focusing only on the inter-industry GVC relations neglects another potentially important source of FVAS effects heterogeneity - country heterogeneity. Path

Table 3.5: FVAS split by partner's business function

	(1)	(2)	(3)	(4)
Labor	0.56***	0.56***	0.57***	0.56***
	(0.01)	(0.01)	(0.01)	(0.01)
Capital	0.26***	0.25***	0.26***	0.26***
	(0.01)	(0.01)	(0.01)	(0.01)
R&D business function	0.26***	0.25***	0.28***	0.23***
	(0.06)	(0.06)	(0.05)	(0.06)
Fabrication business function	0.25***	-0.95**	0.52***	0.23
	(0.05)	(0.28)	(0.17)	(0.20)
Marketing business function	0.23***	0.18**	0.20**	0.19**
	(0.06)	(0.06)	(0.07)	(0.06)
FVAS	0.34***	0.42***	0.39***	0.35***
	(0.06)	(0.05)	(0.06)	(0.07)
FVAS from R&D	0.68***	0.47*	0.75**	0.84***
	(0.20)	(0.24)	(0.35)	(0.19)
FVAS from Fabrication	0.46**	0.43*	0.98***	0.94***
	(0.15)	(0.19)	(0.18)	(0.21)
FVAS from Marketing	0.26	0.31	0.29	0.25
	(0.22)	(0.23)	(0.22)	(0.19)
Fabrication business function	-	1.03***	-	-
x FVAS from R&D	-	(0.33)	-	-
Fabrication business function	-	-	-0.15	-
x FVAS from Fabrication	-	-	(0.25)	-
Fabrication business function	-	-	-	0.09
x FVAS from Marketing	-	-	-	(0.26)
Time effects	Yes	Yes	Yes	Yes
Country-industry effects	Yes	Yes	Yes	Yes
Observations	23,023	23,023	23,023	23,023
Adjusted R-squared	0.53	0.52	0.53	0.53

**** p<0.01, ** p<0.05, * p<0.1.*

Table 3.6: Intra-industry GVC participation

	(1)	(2)	(3)
Labor	0.56***	0.56***	0.56***
	(0.01)	(0.01)	(0.01)
Capital	0.25***	0.25***	0.25***
	(0.02)	(0.02)	(0.02)
R&D business function	0.04	0.04	0.04
	(0.06)	(0.6)	(0.06)
Fabrication business function	0.05	-0.5	0.05
	(0.06)	(0.07)	(0.06)
Marketing business function	0.00	-0.00	0.00
	(0.06)	(0.07)	(0.06)
FVAS-rest	0.80***	0.74***	0.80***
	(0.05)	(0.05)	(0.05)
FVAS-intra	1.95***	1.98***	1.99***
	(0.18)	(0.18)	(0.24)
FVAS-rest	-	0.14**	-
x Fabrication business function	-	(0.06)	-
FVAS-intra	-	-	-0.09
x Fabrication business function	-	-	(0.28)
Time effects	Yes	Yes	Yes
Country-industry effects	Yes	Yes	Yes
Observations	23,023	23,023	23,023
Adjusted R-squared	0.53	0.52	0.53

*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

dependency also plays a role as GVC participants from developed countries may enjoy greater value-added due to their traditionally favorable position on the market. Following Kummritz (2015) we suspect these effects to be distinct in highly, more, and low-developed countries. We, therefore, make use of a nested model in which FVAS measures interact with a development group dummy.

The results in column 1 of Table 3.7 show that returns to the general GVC participation are the same across the board. These results are in line with those reported by Kummritz *et al.* (2017), who found that country development status did not influence GVC participation effects. However, if we distinguish between the business function of the GVC partner, country development matters as column 2 shows. The R&D-related GVC participation is linked to more value-added for low-developed countries than for more and high-developed countries. It is perhaps no surprise that GVC participation with R&D-oriented partners gives the most benefit to the low-developed countries as those countries can profit from knowledge transfer. Contrarily, fabrication-related GVC participation is beneficial more for more and high-developed countries. This hints at the fact that outsourcing production to countries with cheap labor is profitable mainly for these two development groups - the receiving side of the outsourcing does not profit as much as the dominant players of the GVC.

3.5 Conclusion

In this paper we have analyzed the interplay between GVC participation and value-added, illustrating the heterogeneity of GVC participation effects depending on stages of production which were proxied by functional specialization. We have thus bridged the literature dealing with qualitative questions of GVCs such as its hierarchy (Gereffi *et al.* 2005) and quantitative papers focused mainly on descriptive statistics (Timmer *et al.* 2014) or coming short of distinguishing between functional specialization of the GVC partners (Kummritz 2015). There is a strong positive association between value-added and GVC participation - this effect is even more important for fabrication-oriented industries. This likely stems from the closer links in a more rigid hierarchy present in manufacturing sectors (Gereffi *et al.* 2005) which induces technology gains (Ernst & Kim 2002) and results in process upgrading.

By distinguishing between FVAS related to R&D, fabrication, and marketing business function of the GVC partners, we have revealed the second dimension of heterogeneity in GVC participation effects. Because the structure

Table 3.7: Using country development group dummy as an interaction term with FVAS

	(1)	(2)	(3)	(4)
Labor	0.57***	0.57**	* 0.57***	0.57***
	(0.01)	(0.01)	(0.01)	(0.01)
Capital	0.25***	0.25***	0.25***	0.25***
	(0.01)	(0.01)	(0.01)	(0.01)
R&D business function	0.04	0.28***	0.26***	0.27***
	(0.05)	(0.06)	(0.07)	(0.06)
Fabrication business function	0.05	0.27***	0.25***	0.28***
	(0.05)	(0.06)	(0.06)	(0.07)
Marketing business function	0.00	0.18**	0.19**	0.17**
	(0.06)	(0.06)	(0.07)	(0.06)
FVAS	0.64***	0.33***	0.38***	0.32***
	(0.07)	(0.09)	(0.11)	(0.09)
FVAS x low-developed	0.02	-	-	-
	(0.09)	-	-	-
FVAS x high-developed	-0.05	-	-	-
	(0.08)	-	-	-
FVAS from R&D	-	0.45*	0.70**	0.81***
	-	(0.22)	(0.25)	(0.23)
FVAS from Fabrication	-	0.48***	0.93***	0.92***
	-	(0.11)	(0.17)	(0.12)
FVAS from Marketing	-	0.19	0.25	0.22
	-	(0.16)	(0.22)	(0.18)
FVAS from R&D	-	0.81**	-	-
x low-developed	-	(0.26)	-	-
FVAS from Fabrication	-	-	-0.47*	-
x low-developed	-	-	(0.22)	-
FVAS from Marketing	-	-	-	0.12
x low-developed	-	-	-	(0.24)
FVAS from R&D	-	-0.11	-	-
x high-developed	-	(0.19)	-	-
FVAS from Fabrication	-	-	-0.15	-
x high-developed	-	-	(0.17)	-
FVAS from Marketing	-	-	-	0.03
x high-developed	-	-	-	(0.14)
Time effects	Yes	Yes	Yes	Yes
Country-industry effects	Yes	Yes	Yes	Yes
Observations	23,023	23,023	23,023	23,023
Adjusted R-squared	0.53	0.53	0.53	0.53

**** p<0.01, ** p<0.05, * p<0.1.*

of GVC participation changes across the production process, the aggregate effects may mask the true consequences of GVC hierarchy and technology gains. Deepening GVC participation with a partner focused on marketing provides significantly fewer benefits than R&D and fabrication-related GVC participation suggesting the unfavorable position of industries engaged in late fabrication stages, such as assembly. GVC hierarchy and severe competition in such tasks is the culprit of the uneven value-added distribution (Gereffi *et al.* 2005).

Furthermore, countries could be particularly affected by GVC participation based on their development. By allotting the covered countries to groups of highly, more, and low-developed economies, we were able to show that whereas low-developed countries benefit from R&D-related GVC participation more than others, the opposite is true for fabrication-related GVC participation. Yet again, these findings support both the notion of technology transfer from countries with more competencies to those with fewer competencies. Fabrication-related GVC participation is less profitable for low-developed countries likely because of their relatively weak competitive advantage of cheap labor in this particular business function. Generally, we did not find evidence supporting or the hypothesis of the global North benefiting more greatly from GVC participation than the global South.

Except for looking deeper into the functional upgrading of industries and countries, it is also worthwhile to investigate the heterogeneity of the GVC effects among income groups of individuals. Examining the association between wage distribution and GVC participation should be the next step in this line of research. Similarly, expanding the data sample to cover more developing economies is a crucial step to informed development policy. More can be also said about the drivers of the heterogeneity of GVC participation effects. As an example, R&D expenditures may stimulate technology gains from GVC participation through greater absorption capacity Mancusi (2008). Policy would then be able to focus on increasing the benefits of GVC participation as well as on mitigating the potential harm it causes.

Chapter 4

Heterogeneity of GVC Participation Effects and Its Catalysts

4.1 Introduction

A growing body of economic papers argues that although beneficial on aggregate, international trade creates winners and losers. The losers can be societies previously focused on an outsourced industry (Autor et al., 2016), firms in subservient global value chain (GVC) positions (Gereffi et al., 2005a), but also the whole economies which miss their growth potential through misguided policies (Baldwin, 2016a). We set out to show that GVC participation indeed spurs economic growth heterogeneously, i.e., the relative development of the participating economies influences the way these economies benefit from the participation and that its effects can be further influenced by policy, particularly by building a knowledge base in an industry via research and development (R&D) spending. We further strengthen this line of argumentation by showing that even the way foreign direct investment (FDI) links to value-added depends on R&D.

Ever since Ricardo, international trade has been recognized as one of the drivers of economic development (Ricardo, 1891). Comparative advantage makes the developed economies specialize in capital and high-skill labor-intensive industries whereas the low-skill labor-intensive sectors were outsourced to the developing countries (Heckscher 1919). Winners and losers were easily identified in this model. Low-skill labor in developed economies faces new competition whereas high-skill labor and capital raise their returns because of their relative scarcity. This model becomes less relevant with rising substitutability of the factors of production as the same products can often be produced by a variety of input factors mixes Sala & Trivín (2018). Factors of production thus compete with one another as the same product can be produced either by a process relying on manual labor and rudimentary devices or a process based on high-skill labor and sophisticated machines. The distinction between winners and losers of international trade thus becomes increasingly obscured.

With ever-decreasing coordination and transportation costs, the competition shifted from final and intermediary products to tasks and competencies (Grossman & Rossi-Hansberg, 2008; Baldwin, 2016). The unbundled production organized itself into complex value chains which often span around the globe using various competency clusters (Bettiol et al., 2017). value-added of the production is unevenly distributed within the GVCs and reflects the GVC hierarchy which is, in turn, dependent on the competencies of the GVC participants (Gereffi *et al.* 2005). However, the empirical analysis of the GVC participation effects often neglects the competencies of firms or competency levels of sectors as they are difficult to estimate. Linking the technological competency approximated by R&D stock with GVC participation measures is the main contribution of this paper.

The qualitatively oriented literature describing GVC hierarchy and the possibility of upgrading within GVCs has worked extensively with the notion of technology playing a part both in task distribution and in the likelihood of functional upgrading (Humphrey & Schmitz 2002; Gereffi *et al.* 2005). But the empirical inquiry has been, to the author's knowledge, scarce. This paper attempts to bridge this strand of literature with the empirical analysis of GVCs as done e.g. by Timmer *et al.* (2014) or Kummritz (2015). Although R&D stock is a rudimentary proxy for technological capacity, it is nonetheless the first step into the empirical analysis of the GVC and technology interplay and it can serve as a first step for deeper analysis potentially using more granular data that enable a more precise specification.

GVC hierarchy is not defined solely by technological competencies. Countries that managed to put their firms in the center of the production processes often benefit from their past success. They retain the technological prowess but the fact that they functionally specialize in headquarter tasks indicates strong path dependency (Stöllinger 2021). FDI stock, both outward and inward, suggests integration in the global economy with a relatively strict hierarchical mode of governance. Indeed, the investments correspond closely to the GVC participation measures (Comotti et al., 2020). Outward FDI stock can thus serve as a complementary indicator to the R&D stock which focuses solely on the competencies.

We attempt to relate GVC participation with competencies by using the World Input-Output Database (WIOD) and combining it with R&D expenditures in 49 Czech industrial sectors over the 2000-2014 period. Using foreign value-added share as a proxy for GVC participation, R&D capital stock as a proxy for competency, and FDI stocks as a complementary indicator reflecting GVC hierarchy creates an opportunity to inspect whether increasing competency or hierarchical standing indeed corresponds to more beneficial GVC participation. Evidence in support of this hypothesis can serve as an additional argument for spurring R&D spending and designing policies aiming to attract foreign investment.

The analysis of Czech sectoral data shows that the benefits of GVC participation are not uniform across the board. GVC participation benefits are mainly driven by links to partners with a higher level of economic development. The benefits are further stimulated by R&D stock of the respective sector. This is not the case for links to less-developed countries. The relationship between inward FDI stock and value-added is positive but that of outward stock is negative.

The paper is structured in the following way: section 2 introduces the theory, explains the key concepts, and review papers relevant to the study. Section 3 presents the data and methods. section 4 discusses the empirical results, and section 5 concludes the paper.

4.2 Theory, concepts, hypotheses

The issue of economic development is the cornerstone of economic thought. Long-term economic growth is strongly linked to inclusive institutions (Acemoglu & Robinson 2012). Short-term growth has become recently more dependent on the way the countries manage to link themselves to the global economy (Baldwin, 2016). With new insights about the hierarchy reigning in the GVCs (Frederick, 2014), the distribution of value-added in the world economy and its driving factors has become relevant for developing countries, and also for developed countries that try to catch up with their still more advanced peers. It thus no longer suffices to ask what factors drive economic growth.

The question of which factors only influence the value distribution in the world economy, and which also spur economic development has become pressing.

One of the prime suspects of a factor influencing value-added distribution as well as long-term economic development is R&D investment. Griliches (1979) introduced a framework for estimating R&D returns, and since then, research has relatively consistently presented evidence of R&D stock being related to greater value-added (Hall *et al.* 2010). This is not the case only for direct returns, i.e., the effects on the investing firm or industry, but also on the surrounding economy through spillovers. Indeed, the spillovers are present, and although they do not remain constant over time (Lucking *et al.* 2018), they stay relevant and both statistically and economically significant (Lucking et al., 2020).

The most recent meta-analysis by Ugur et al. (2020) confirms that the direct R&D returns are positive along with positive and statistically significant spillovers. However, there is a strong indication of heterogeneity of the spillovers as they are significant only for the subset of the OECD countries. The authors attribute the heterogeneity to the absorptive capacity - the existing R&D stock helps the firms benefit from R&D spending different from their own. The logic of absorptive capacity can, however, be used also for technology transfer via GVC participation. GVC participation could work hand in hand with R&D spending in the quest of economic development.

Hypothesis 1. The benefits of GVC participation are stimulated by R&D stock.

Effects of GVC participation can be heterogenous not just because of the characteristics of the respective country - such as absorptive capacity. GVC participation itself can vary in terms of power relations within the GVCs (Frederick, 2014). Distinguishing between the source countries of the GVC participation, it is possible to investigate how R&D stock stimulates either GVC participation with developed or developing countries. Given the thesis of uneven power relations defining value-added distribution (Kaplinsky, 2000), the effect of absorptive capacity should be most pronounced in interaction with GVC participation with developed countries.

Hypothesis 2. R&D stock stimulates the benefits of GVC participation with developed countries.

Another factor codetermining the value-added distribution is FDI, one of the modes of integration into the global economy. Whereas countries with sufficient size and resources can shield their industries from foreign competition and build domestic technological capacity, smaller economies rather pursue the strategy of attracting FDI with the hope of technology spilling over to their domestic firms (Gereffi, 2009). Such a strategy works. (Demena & van Bergeijk 2017) provide a meta-analysis of FDI spillovers showing, that despite publication bias, the spillovers are positive and statistically significant.

FDI is also instrumental in GVC architecture. As Amador & Cabral (2016) note, multinational enterprises (MNE) use FDI to set up a new chain. Such a GVC is highly hierarchical with the dominant MNE positioned in its center. Part of inward FDI thus can be assigned to deepening GVC participation, particularly in the position of a junior partner. But even a strictly hierarchical GVC can provide benefits in terms of technology spillovers. The question is whether R&D stock provides absorptive capacity to industries with significant inward FDI stock and thus stimulates the spillovers.

Hypothesis 3. The FDI spillovers are stimulated by R&D stock.

GVC participation can indeed happen through FDI which suggests a strong hierarchical organization. Is such a setting beneficial for the receiving country? Or is it the investing country that profits? Or does it depend on whether the GVC participation happens with developing or developed countries? We hypothesize that tight and hierarchical relationship provides a breeding ground for technology spillovers. It might be that in the long term, such a GVC architecture hinder the development of the less developed partners, but it nonetheless stimulates the technology transfer at the given moment.

Hypothesis 4. The FVAS benefits are stimulated by inward FDI.

4.3 Data and methodology

Although our analysis concerns Czech sectors, we are interested in all their international links. We thus use the World Input-Output Database - release 2016 provides a panel of 53 industries in 43 countries over the period 2000-2014 - using just the data for Czech sectors (Timmer *et al.* 2015). WIOD also provides socio-economic accounts for value-added, capital, and labor employed which we use in our model. All currency-based variables (i.e., all variables except for labor which is calculated as full-time equivalents) are converted to US dollars and use 2010 prices. To get a proxy for GVC participation, we calculate foreign value-added share measures (FVAS) following Los *et al.* (2015). FVAS, a measure of international integration, tells us how much of the total value-added of the particular GVC is produced abroad.

$$FVAS_{CZE}(j) = \frac{\sum_{c,k:c \neq CZE} VA(j)(c,k)}{\sum_k VA(j)(c,k)} \tag{4.1}$$

where $VA(j)(c,k)$ describes value-added of a Czech industry j produced in industry k of country c, its GVC partner. The value-added created in each industry is given by the vector $\mathbf{g}$:

$$\mathbf{g} = \hat{\mathbf{v}}(\mathbf{I} - \mathbf{A})^{-\mathbf{1}}(\mathbf{Fe}) \tag{4.2}$$

In this equation, $\hat{\mathbf{v}}$ is a matrix with value-added over gross output on its diagonal, $(\mathbf{I} - \mathbf{A})^{-\mathbf{1}}$ is the standard Leontief inverse, $\mathbf{F}$ is the matrix of the final output, and $\mathbf{e}$ is the summation vector.

FVAS is easy to slice. We can then discern FVAS coming from a set of different countries, differentiating the effects of GVC integration with the old EU member states, with the new EU member states, with other OECD countries, and with the rest of the world. The equation below shows the calculation of FVAS from other OECD countries (where we disregard the Czech Republic and EU countries which are also OECD members). The other country groups are calculated accordingly:

$$FVAS - OECD(j) = \frac{\sum_{c,k:c \in OECD} VA(j)(c,k)}{\sum_k VA(j)(c,k)} \tag{4.3}$$

Having the information about sectoral GVC participation, we want to combine it with R&D data to investigate the interplay between R&D capacity and GVC participation effects. Eurostat provides sectoral data on R&D expenditure for Czechia in the years 2005-2018. After readjusting for different sectoral granularity of the datasets and putting the R&D expenditures into 2010 prices in USD, we calculate R&D capital stocks. This is to reflect the lagged effect of R&D expenditure on the value-added. We follow Hall et al. (2010) in the calculations.

$$R_t = (1 - \delta)R_{t-1} + r_t \tag{4.4}$$

The iterative approach requires R&D capital stock at time 1. Assuming constant growth rate of the R&D expenditures and a constant depreciation rate (Hall *et al.* 2010), we arrive at:

$$R_2 = \frac{r_1}{g + \delta} \tag{4.5}$$

Hence, we lose the first observation and arrive at a dataset spanning from 2006 to 2015 for 49 sectors.[1]

In the second part of the empirical analysis, we use FDI stock data as they are reported by the Czech National Bank. Their sectoral classification is different from WIOD, so we are forced to drop a portion of sectors and use only those where the two classifications overlap. This naturally introduces issues of limited dataset and the potential bias of the results as the missing values are likely not distributed at random. Indeed, they are not, as the majority of the missing values are in the services sectors. Thus, the results with FDI data should be interpreted with caution and the realization that the underlying data represent disproportionately the manufacturing sectors.

Table 4.1: Summary Statistics

	N	MEAN	SD	MIN	MAX
Capital stock (CZK millions)	470	15,666	38,422	0	340,430
Labor (FTE thousands)	470	151	144	1	584
value-added (CZK millions)	470	3,152	3,268	4	19,116
R&D Stock (CZK millions)	424	166	243	0	2,137
FVAS total	470	0.24	0.12	0	0.56
o/w FVAS from high-developed	424	0.05	0.05	0	0.21
FVAS from less developed	424	0.19	0.08	0	0.38
Inward FDI Stock (CZK millions)	243	45,205	76,968	-44	661,362
Outward FDI Stock (CZK millions)	243	5,239	22,148	-1,487	233,504

Source: Author's computations

The empirical strategy follows Kummritz *et al.* (2017). We estimate the model based on a standard production function.

$$Y(A, F) = F_1(FVAS, ...)F_2(K, L) = AL^{\beta_1}C^{\beta_2}K^{\beta_3}FVAS^{\beta_4}e^{u} \tag{4.6}$$

where A is the shared technology for all industries, L and C are the labor and capital inputs respectively, K is the R&D stock and FVAS is the measure for GVC participation, and u is the error term. $\beta_1, \beta_2, \beta_3, \beta_4$ are the respective

[1] As in Pleticha (2021), we omitted the sector.*manufacture of coke and refined petroleum products* because of the highly unstable price index.

elasticity coefficients. Taking a logarithmic transformation and controlling for a common technology development, we get:

$$y_{jt} = a_j + \beta_1 l_{jt} + \beta_2 c_{jt} + \beta_3 k_{jt} + \beta_4 FVAS_{jt} + \lambda_t + u_{jt} \tag{4.7}$$

The model specification suffers from the obvious issue of endogeneity. It is therefore an exploratory analysis that merely suggests potential causal links between GVC participation, R&D, FDI, and value-added.

4.4 Results

Before delving into the specific hypotheses, we run a simple, benchmark model to relate our results to previous research. The estimates of labor and capital shares fall in line with studies that used similar data - so are the returns to R&D (Hall *et al.* 2010; Sveikauskas 2007; Ortega-Argilés *et al.* 2010). GVC participation is related to greater sectoral value-added which also mostly confirms the finding of other scholars (Kummritz *et al.* 2017; Kordalska *et al.* 2016). Splitting GVC participation into that linked to the high- and less-developed countries (see the appendix for the country groups) reveals that Czech industries benefit markedly by GVC participation with the high-developed sort.

This cannot be bluntly interpreted as evidence for technology transfer though. GVC participation with high-developed countries serves also as an opportunity for functional upgrading - integrating and potentially moving up in the GVC hierarchy. However, such a distinction suggests that GVC participation with less-developed countries does not benefit the Czech industries and thus the premise of a value chain dominated by the Czech firms where the Czech firms reap disproportionate value-added is likely false. This further suggests that economic strategies aiming at diversification of foreign trade links - specifically towards the less developed countries which are considered as a unique trade opportunity - are not fully based on empirical evidence(Hesse *et al.* 2009). However, this could be also caused by the non-linear relationship between productivity and export diversification as (Xuefeng & Yaşar 2016) show.

To see whether R&D capacity interacts with the GVC participation, we investigate the specification of models 3, 4, and 5. Whereas the general measure of GVC participation remains the same when interacted with R&D stock (model 3), splitting the GVC participation once again provides a more elaborate picture. It is only the GVC participation with high-developed partners which is stimulated by greater R&D stock. These results suggest that, in the context of Czech industries, R&D stock serves rather as an absorptive capacity proxy (Griffith *et al.* 2004). The notion of using the technological capability to benefit from links with less developed partners remains, as in the previous case, unfounded.

Table 4.2: GVC participation and R&D stock; interactions

	(1)	(2)	(3)	(4)	(5)
Capital	0.35***	0.36***	0.36***	0.36***	0.36***
	(0.05)	(0.05)	(0.03)	(0.03)	(0.03)
Labor	0.68***	0.67***	0.67***	0.67***	0.67***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
R&D Stock	0.08**	0.07**	0.01	0.06	0.53*
	(0.03)	(0.02)	(0.04)	(0.04)	(0.30)
FVAS	2.21*	-	-2.14	-	-
	(0.98)	-	(3.04)	-	-
FVAS x R&D Stock	-	-	0.35	-	-
	-	-	(0.23)	-	-
FVAS from high-developed	-	7.44*	-	-12.60	7.17
countries	-	(3.14)	-	(9.74)	(3.29)
FVAS from high-developed	-	-	-	1.63*	-
countries x R&D Stock	-	-	-	(0.74)	-
FVAS from less-developed	-	-3.84	-	-4.44	-10.59
countries	-	(3.42)	-	(3.44)	(5.71)
FVAS from less-developed	-	-	-	-	0.50
countries x R&D Stock	-	-	-	-	(0.41
Time effects	Yes	Yes	Yes	Yes	Yes
Country-industry effects	Yes	Yes	Yes	Yes	Yes
Observations	415	415	415	415	415
Adjusted R-squared	0.86	0.87	0.87	0.87	0.87

**** p<0.01, ** p<0.05, * p<0.1.*

Foreign value-added share is only one way how to look at the GVC participation. A measure reflecting a rather stricter GVC integration is FDI. FDI and FVAS measure (and even R&D stock) clearly describe the same complex phenomenon which is reflected in the instability of the coefficient estimates once inward and outward FDI stocks are added into the model.[2] Including the

[2]The instability is partially caused also by the limited dataset. That is the case mostly with the R&D returns. They seem to be inflated by the fact that the dataset reflects only those industries which in FDI database provided the Czech National Bank.

FDI stocks renders FVAS insignificant. But it also shows the inward FDI is remarkably beneficial for greater value-added. This is not the case with the outward FDI stock which is related to less value-added.

Whereas the inward FDI stock has been repeatedly related to greater productivity and thus greater value-added (Demena & van Bergeijk 2017), the outward FDI stock's negative sign is not well-established in the literature (Herzer 2010; Lee 2010). The reason for that might be the fact that outward FDI at the industry level means outsourcing of certain classes of tasks. Sometimes it may be tasks with less value-added. In such cases, the effect on productivity would be positive, since the respective industry could focus on tasks with greater value-added. If the industry is not a technological leader, however, it may decide to focus on tasks where it enjoys a comparative advantage. This in turn means that it outsources tasks with greater value added than the tasks it keeps domestically.

If, for instance, an automotive firm engages in outward FDI, it is likely that it outsources mainly the assembling parts of the production chains. The services, which are likely to fall into different categories of our sector classification remain in-house. This means that even if the outward FDI benefits the firm and the economy, it, at the sectoral level, relates to value-added negatively.

Such a narrative corresponds with the findings of the second model (column 2). A more R&D intensive sectors lose less from outward FDI.[3] Indeed, being more technologically advanced to begin with possibly means that the high value-added tasks are optimal to keep in-house. The negative relationship is then still present but diminished. Finally, the interaction of inward FDI stock and R&D stock is statistically irrelevant. This is an indication that in the more hierarchical organization of the value chain, the absorptive capacity is less relevant than in the looser organization. Such a result is also in line with the intuition behind qualitative analysis provided by Kaplinsky & Morris (2000). Indeed, the value chains organized in a looser fashion provide greater opportunity to functionally upgrade - and that is achieved by building up absorptive capacity including R&D stock.

[3]The interaction can also be interpreted such that outward FDI increases the R&D returns. The interaction term cuts both ways.

Table 4.3: GVC participation, R&D stock and FDI; interactions

	(1)	(2)	(3)
Capital	0.35***	0.36***	0.36***
	(0.03)	(0.04)	(0.04)
Labor	0.65***	0.65***	0.65***
	(0.04)	(0.04)	(0.04)
R&D Stock	0.32*	0.35	0.40
	(0.11)	(0.23)	(0.23)
FVAS	-0.25	-0.20	-0.24
	(0.82)	(0.52)	(0.83)
Inward FDI stock	0.16***	0.15***	0.11
	(0.04)	(0.04)	(0.06)
Outward FDI stock	-0.06*	-0.12**	-0.06**
	(0.03)	(0.04)	(0.03)
Inward FDI stock x R&D stock	-	-	0.00
	-	-	(0.01)
Outward FDI stock x R&D stock	-	0.01*	-
	-	(0.00)	-
Time effects	Yes	Yes	Yes
Country-industry effects	Yes	Yes	Yes
Observations	234	234	234
Adjusted R-squared	0.88	0.88	0.88

**** $p<0.01$, ** $p<0.05$, * $p<0.1$.*

4.5 Conclusion

In this paper, we have analyzed the heterogeneous effects of R&D, FDI investment, and GVC participation using Czech sectoral data. We have shown that it is mainly GVC participation with high-developed countries that is linked with higher value-added. Such a positive relationship is further enhanced by higher R&D stock. Using a related measure for foreign trade integration, FDI, revealed a positive relationship with value-added in the case of inward FDI and negative in the case of outward FDI. The negative relationship between outward FDI and value-added is mitigated by R&D spending. The counterintuitive results of outward FDI can possibly be attributed to outsourcing tasks with greater value-added. However, more research is needed to confirm such a claim.

Our analysis has naturally its limits. The model specification does not allow for causal interpretation and thus, the results should be interpreted only in an exploratory fashion. Moreover, the FDĂI data are far from complete which makes the results of the regression including FDI biased towards the true relationship present solely in manufacturing. Firm-level data would enable us to circumvent such issues and even deal with endogeneity but a comprehensive dataset including information about firms' suppliers and customers is, to the author's knowledge, currently not available.

The results suggest that R&D stock is a good proxy for the capability of catching up with more advanced economies but, at least for post-transition countries such as the Czech Republic, it does not serve as a sufficient condition for the ability to build a value chain around the domestic industry and use its centrality for its own benefit in terms of value-added distribution. In other words, Czech industrial capabilities reflected in the R&D stock have so far not reached the level with sufficient gravity to functionally upgrade in a substantial way within the existing value chains or organize brand new value chains around those newly acquired capabilities. Such results could either hint to the fact that capabilities are not a deciding factor in the GVC organization or that countries such as Czechia have not yet reached the critical mass of their industrial knowledge.

To decide which one of these hypotheses is true is beyond the scope of this paper. However, future research should address such problems due to their policy relevance. Although R&D research is surely beneficial in its own right, its utility as a tool for succeeding on the global markets is far less clear. Yet the right policy mix of public and private R&D spending, attracting foreign investment, and participating in global value chains is likely necessary both for advanced countries such as Czechia aiming to catch up with their western neighbors as well as developing countries avoiding the middle-income trap.

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Appendix A

Responses to reviewers' comments

A.1 Dr. Micheline Goedhuys

It was with great pleasure that I read the thesis titled 'Essays on the impact of technological change on economic structure'. This fine piece of research addresses some core questions of economic development, namely returns to R&D leading to productivity, and the conditions to benefit from GVC participation for industries and countries, in particular the Czech Republic.

The dissertation consists of an introductory chapter and three substantial research papers. The overall writing style is compact and academic. Let me discuss the chapters in short.

The introductory chapter is short and attempts to link together the research chapters by integrating them through an overarching theoretical framework in about three pages. These are not a light read, but a compression of concepts into one short section, possibly not to attractive for a broader audience. The sections are also not particularly well written. Though these are not the most important parts of the dissertation, an editorial round to improve the readability of the first three pages could add some value to the thesis.

Author: *Thank you for the comments. I have extended rewritten the introductory chapter, explained the key concepts in greater detail and also expanded on the covered literature. Special attention was given to the readability and attractivity of broader audience.*

A.1.1 Chapter 2: Heterogeneity of Returns to Business R&D: What Makes a Difference?

The second chapter estimates the heterogeneity of returns to business R&D. The chapter nicely fits in the tradition of industrial economics and innovation studies, assessing the impact of R&D on firm performance. The chapter contributes to an already rich body of evidence which was mainly based on micro evidence using the firm as the level of analysis and correctly referenced in the text. This paper however is novel in several respects:

1. it takes into account both privately funded and publicly funded R&D efforts in private companies
2. it takes the industry/sector as the main level of analysis
3. this allows to investigating both direct and indirect (spillover) effects of R&D
4. both upstream and downstream spillovers are considered
5. non-linearities in the R&D returns are assessed
6. the effects of the economic crisis are assessed by splitting the period of analysis in the estimations
7. it uses data from the Czech Republic, I particular from the CZSO

Hence the topic is analysed from many novel perspectives and the chapter presents therefore a clear picture of the R&D returns and the heterogeneity along the different dimensions addressed (private/public; direct and indirect; back and forward; and combinations thereof).

The analysis is rigorous: the data and construction of variables are clearly explained, summary statistics are presented and briefly discussed. The results are well presented and interpreted. The discussion is helpful in understanding the tables. The findings are interesting, intuitively clear. In the conclusion they are put into perspective by comparing to findings from other studies. Some of the drawbacks of the approach, e.g. that intra-industry spillovers are not detected by this approach, are acknowledged.

The entire chapter is written in a relatively compact way, but I could nevertheless follow all the logical steps, except in the discussion on rent spillovers. The discussion on page 13 related to the distinction between technology and rent spillovers remains quite unclear to me. I would suggest to give it a bit more space and explain what is meant by rent spillovers, what the exact underlying mechanism is and how it matters for the analysis. This could be done in a footnote, or in the text itself. Also in the results (p.19) it is briefly mentioned but I cannot understand from the discussion of the results what is exactly found.

Another question I have relates to the non-linearity analysis. It would be my expectation that the threshold is very industry specific. I wonder to what extent it is meaningful to estimate a threshold over all industries included in the sample. A short elaboration could be meaningful.

Author: *I have added a discussion about rent spillovers where they are defined precisely according to the distinction of Griliches (1979). In the old version of the manuscript, the term was used fuzzily. I have made it more accurate which also slightly affected the interpretation of the results.*

You are correct that the exercise of looking for a single threshold across all industries is unlikely to find one. Unfortunately, a specification which would allow for industry-specific threshold introduces too many variables in the estimation. I have added a disclaimer about the threshold regression and a suggestion about the industry-specific thresholds with more granular data.

A.1.2 Chapter 3: Who Benefits from Global Value Chain Participation? Does Functional Specialization Matter?

Chapter three studies heterogeneity in the effects of GVC participation. It does this along a number of interesting dimensions:

1. own functional specialization
2. functional specialization of the partners
3. level of development of the country

The theory and concepts and the sources of heterogeneity are well discussed in section 3.2. However the hypothesis development section is less clear, as are the hypotheses themselves. They are relatively vague.

For instance hypothesis 1, 'Increasing GVC participation benefits more fabrication-oriented industries' raises the question 'more than what'? Do you mean: 'GVC participation is more beneficial (how measured?) to fabrication oriented industries than to industries oriented towards other business functions such as marketing'?

The lead-up to hypothesis 2 is also rather unclear and seems a bit speculative. In the explanations toward H1, the quote "GVC participation leads to knowledge spillovers but that is likely to happen only across certain kinds of business functions such as R&D" seems difficult to interpret against the earlier statement that "knowledge is easiest transferable in codifiable form [...] fabrication oriented industries benefit most."

H3 could have been formulated as 'Industries benefit from GVC participation irrespective of a country's level of development'.

In a first reading, without prior knowledge of the empirical approach and results, the logic leading to the three hypotheses is difficult to follow. I wonder if the hypotheses development provides any value added and I think more open research questions related to the impact of functional specialization could have worked well.

Author: *The hypotheses were supposed to serve as guiding claims to the reader. Their purpose was not to serve as a backbone for the empirical analysis where the sole function of the regression estimation would be their refutation. That is why they were relatively vague. That said, I agree that they provide an unnecessary layer of complexity to the manuscript. That is why I have removed them from Chapter 3 and adjusted section 3.2. I have added a footnote specifying what is meant by "benefit" from GVC participation.*

I have also expanded on my argumentation. I believe that the fact that "knowledge is easiest transferable in the codifiable form" is in line with the suspicion that fabrication-oriented industries can profit from R&D-focused peers. Since fabrication relies on machinery and comparably rigid processes, the knowledge involved is likely more codifiable and codified than it would be the case with management-oriented industries. Although management practices can be emulated, I believe that with the assistance of a GVC partner, it is easier to operate advanced machinery than create sophisticated managerial structures.

The empirical approach uses data from the WIOD and functional specialisation data from 35 industries in 40 countries. The method is well explained and appropriate for the research questions. The focus in the estimations on the fabrication business function is apparent, however, it is not always clear why exactly fabrication is explored more in detail (eg in T.3.4 model 4) and why the other interactions (RD and marketing interacted with FVAS) are not presented. Are they not relevant?

Author: *The underlying motivation for the thesis was to explore whether and how GVC participation can help middle-income countries to develop. The first step of such integration is often fabrication business function so the thesis explores fabrication in the greatest detail. I have added this motivation in 3.2.*

Comparing the results of table 3.4. and 3.5 I was a bit puzzled by the large change in coefficient of the R&D, fabr. and mkt business function variables, due to the split of FVAS into three variables (FVAS from RD, FVAS from fabr, FVAS from mkt). This for instance does not occur in Table 3.7 when FVAS is split by level of development of the country. All in all, though the choice of models could be better justified, the results are interesting, well presented and discussed in an insightful manner.

Author: *The changes in coefficients of business function variables likely relate to the relationship between those variables and FVAS split based on the partners' business function. This could be either due to colinearity which we ruled out by statistical tests (VIF) or by omitted variable bias. This would mean that FVAS from a particular business function is negatively related to the business function itself. In other words, specific GVC participation makes functional specialization less relevant. To give an example, R&D-oriented industry benefits from its business function itself, but it also benefits from being engaged with other R&D-focused industries. However, greater functional specialization decreases the likelihood of such engagement. This is a mere hint of the interactions, as the picture is more complex due to different kinds of business specialization all acting at the same time.*

A.1.3 Chapter 4: Heterogeneity of GVC Participation Effects and Its Catalysts

Chapter four continues along this line of research and focuses on Czech sectors' different types of international links, including GVC participation and FDI and R&D stocks. The empirical approach is comparable to the approach of chapter three.

I have the following comments on this chapter:

1. I believe there is a part of the text missing on top of page 55.
2. Also on page 55, I do not see how you can jump to the conclusion that the

results are in contradiction with strategies that see trade with developing countries as beneficial.

3. Table 4.2: what is the difference between model 1 and model 3?
4. Table 4.2: why is R&D stock left out in model 2?

Author: *I have revised the problematic parts of the text and toned down the claims about policy. R&D in Table 4. is missing by accident and it has been added.*

The conclusion is fine, and acknowledges the limitations of the study. The chapter is interesting to the context of the Czech Republic.

In sum, I think this thesis meets the quality criteria generally in place for admission to a public defense. The dissertation contributes to the body of academic knowledge; the approach is original; the structure, analysis and processing of the data have been done well; the methodology used is appropriate; there is balance in the amount of volume of text and analysis. I believe some parts of the thesis are published or in a peer review process. I made some comments but they are not prohibitive for admission to the defense. The candidate can opt to use the comments to improve the manuscript.

A.2 Martin Lábaj

The thesis is composed of three papers that investigate direct and indirect returns to RnD, links between global value chains participation and sectoral productivity, and the effects of RnD and FDI on the benefits provided by global value chains participation. Introduction to these papers summarizes the main results and provides a comprehensive links between their partial results.

First, I highly appreciate this form of a dissertation thesis. Namely that it is based on research papers submitted (ready for a submission) to international journals. Moreover, all three papers are closely related and explore various aspects of RnD, FDI and GVC participation and their links to productivity. As this is not always the case. So, it has been rather straightforward to put the results together and present them as a rather broad study on these issues.

Thus, as two out of three papers are already published in international journals (to my best knowledge) they proved to contribute to our understanding of the explored issued. In particular, the publication in *Structural Change and Economic Dynamics* is a great achievement in this stage of research career.

If not yet published, the third paper presents original research study and provides new empirical findings that could be published in recognized international journal.

The thesis is based on relevant and up-to-date literature. Literature review in all chapters provides well elaborated currents state of the research in particular fields of research. The thesis would be defendable at my home university, University of Economics in Bratislava, and as far as I can foresee it would be defendable at other recognized institutions such as WU Wien or Faculty of Economics at the University of Coimbra with which I do have some experiences.

I do not have any major comments. There are few suggestions I provide below that I hope could make the text more readable for audience.

In the introduction, author should pay an attention to the distinction between functional specialization in terms of industrial structure and functional specialization in terms of tasks. Rather sharp jump is made in the introduction from one concept to the other one without any explanation. I would suggest to make this difference explicit.

Author: *Thank you for the kind feedback. I have made a substantial revision of the introduction including a better and more explicit presentation of the key notions, specifically the functional specialization.*

A.2.1 Chapter 2: Heterogeneity of Returns to Business R&D: What Makes a Difference?

In Chapter 2, I found the sentence "*Our aim in this study is to address these gaps in an integrated way.*" rather vague. There is a rich literature reviewed above this paragraph and it is not clear which questions are addressed in the paper. I would suggest to be more concrete and elaborate one or two sentences that make this explicit before moving to data description.

Author: *Thank you for the comment. I have made the "novelty claim" more explicit and straightforward.*

A.2.2 Chapter 3: Who Benefits from Global Value Chain Participation? Does Functional Specialization Matter?

Similarly, in the introduction to Chapter 3, I would suggest to state the contribution of the paper and its novelty more explicit. In particular, the third paragraph in 3.1 states that "*This paper contributes to this line of research by exploring the heterogeneity of GVC effects in a novel and more detailed way.*" It is followed by description of data used in empirical analysis and by the main results of the paper, but I missed more direct link to literature to which it contributes new empirical results. What is novel? In which direction goes a more detailed analysis? Referring to which papers it is more detailed? In similar way, the way how you bridge the two strands in the literature, that is very valuable, could be elaborated more explicitly. How the rather qualitative papers motivate/drive your empirical exploration? What has been missing in empirical works by Stroellinger (2021), Timmer et al. (2019) and/or Baldwin et al. (2014)? Similarly, in conclusions, contribution of the paper could be related more explicitly to particular papers. Overall, the originality of the research in this paper is not a question but should be made more explicit for interested readers.

Author: *I have expanded on the description of the way the paper is novel to the literature. Also, I have described in greater detail the added value of the analysis compared to the referred papers, both in the introduction and conclusion.*

Overall, the thesis provides new empirical results on the interplay between private and public RnD spending, GVC participation, FDI and sectoral productivity growth. It is focused on issues that are highly important for an economic development and especially for an economic development of CEE countries. The results provide rigorous understanding of enquired relations and meet high scientific standards from an international perspective. Moreover, they provide useful insights for policymakers, especially for those responsible for industrial policy, structural changes and economic development. From the perspective of a growing importance of well-designed industrial policies over the last decade (and calls for an "industrial renaissance" from European and national policymakers and stakeholders) are the results even more relevant.

A.3 Matěj Bajgar

The dissertation explores the role of R&D and participation in global value chains (GVC) on economic performance. It consists of three substantive chapters, each of which represents an independent research paper.

The dissertation is empirical in nature and studies sources of knowledge with a potential to increase productivity, stemming either from R&D (Papers 1 and 3) or from GVC participation (Papers 2 and 3).

Methodologically, it is based on industry-level data either for Czechia (Papers 1 and 3) or for multiple countries (Paper 2). The estimation specification is derived from a log version of a Cobb-Douglas production function. The estimation techniques used are relatively simple but but transparent and appropriately used, relying on OLS panel regressions with unit and year fixed effects.

The dissertation looks at topics where an extensive academic literature already exists, and it follows the literature in its motivation and methodology. All papers, however, make distinct novel contributions to the literature, primarily by exploring heterogeneity in the estimated effects and, consequently, giving a richer picture and allowing a more detailed interpretation than previous studies.

The principle weakness of all papers is that they do not contain an explicit identification strategy and are not able exclude the possibility of reverse causality or the results being driven by a third factor, and consequently their results only represent conditional correlations and do not have causal interpretation. That said, this shortcoming concerns a vast majority of papers in the relevant literatures, and it is transparently and extensively discussed by the author. It is also helpful that, where applicable, the author discusses related papers that give an indication of the magnitude and direction of the biases that we can expect in the estimates relative to causal effects.

The dissertation demonstrates good knowledge of relevant scientific literature, which is appropriately cited throughout the dissertation.

In conclusion, I have enjoyed reading the dissertation, I have learned from it both in terms of its methodology and its findings, and **I recommend the thesis for defense without substantial changes.**

I add more detailed comments on the dissertation and the individual papers below. As the first two substantive chapters have already been published in academic journals (indexed in the Web of Science), I do not require extensive changes to the analysis, but I indicate some points which deserve additional discussion, require clarification or should be relatively easy to be improved or corrected. **The suggested action is marked in brackets after each comment.**

A.3.1 Chapter 2: Heterogeneity of Returns to Business R&D: What Makes a Difference?

The paper estimates economic returns to business expenditure on research and development (R&D) in the Czech Republic. It uses data for 61 Czech industries over the period 1995-2015.

It follows methodology established in the literature, estimating parameters of an (industry- level) Cobb-Douglas production function augmented with the stocks of R&D capital. It distinguishes between multiple types of R&D capital. Firstly, it distinguishes between each industry's own R&D capital stocks and R&D capital stocks in all industries that are weighted using an input-output matrix. The former measures a combination of the private returns to each firm's own R&D and spillovers across firms operating in the same industry (intra-industry spillovers). The latter captures inter-industry spillovers. Secondly, it distinguishes between public R&D (or, more accurately, publicly funded business R&D), which is financed by government grants (and procurement) and private R&D, which is financed from each firm's own funds or from other sources, such as funds from other firms. The production function is estimated in a log-log form using a simple linear regression with industry and time fixed effects. The paper finds positive direct effects of privately funded R&D but not publicly funded R&D, and positive spillovers from both privately and publicly funded R&D. It additionally finds evidence of the returns materialising only when the stock of R&D capital in an industry exceeds a certain threshold, and evidence of the returns to privately funded R&D increasing in the crisis period 2009-2015.

Overall evaluation

The author asks a relevant question (how high are returns to R&D?) and answers it using appropriate methodology. The analysis is well-motivated and generally well executed. Importantly, the author also carefully discusses limitations of the analysis, in particular with respect to causal interpretation of the results, and indicates expected direction and size of potential resulting biases.

The contribution of the paper to existing literature is well discussed and can be described as incremental, consisting mainly of

- jointly analysing returns to private and public funding for business R&D
- conducting the analysis in the context of a country (Czechia) that was only gradually catching up with the technology frontier during the period of the analysis
- exploring non-linearity in the returns
- exploring heterogeneity in the returns in relation to the economic cycle

Comments

1. The paper attempts to estimate returns to R&D (as per its title) but the estimation coefficients are actually elasticities from the production function, not returns. To obtain returns to R&D, defined as a change in value added corresponding to 1 unit of R&D capital stock, the elasticity needs to be multiplied by a ratio of value added to the R&D capital stock (e.g. for an average industry). See Hall et al. (2010) for a discussion. This is important also because with the stock of publicly funded business R&D being much smaller than the stock of privately funded business R&D, even a smaller elasticity for publicly funded R&D can imply similar returns as those implied for private R&D. [discussion to be added]

   Author: *You are absolutely correct. I have used the term returns as the paper was intended for a broader audience (including policymakers) and the notion of elasticity is not a household term. Only in the model description, where precision is necessary, I believe, I have used the term elasticities. I have added a discussion in Chapter 2: Econometric results to be precise and explain to the reader this inconsistency in terminology.*

2. The extension of the log-log production function in equation 2.6 implies a (non-log) Cobb-Douglass production function where the stock of publicly funded R&D capital is a separate factor of production. Strictly speaking, this would imply that with no public funding for business R&D, the industry value added would be zero. It seems more realistic to consider "knowledge" to be the same factor of production irrespective of how its generation is funded, but allow for public R&D expenditure for being less effective in generating such knowledge. The resulting production function

would not be conveniently additive in logs the way expression 2.6 is, but it would be worth at least discussing the implications of the difference between 2.6 and the more appropriately specified production function. [discussion to be added]

Author: *The specification is indeed chosen such that the extreme cases are not covered. Since I was unable to come up with a more elegant, yet rigorous model, I decided to stick with the old one, and add a discussion of the issue in the "Model and Data" section of Chapter 2.*

3. A citation in the second paragraph makes it sound like Bloom et al. (2013) were the first to estimate spillover effects from R&D, but this is certainly not the case (although their paper certainly was a major methodological step forward in several directions). [a minor modification required]

   Author: *The reference was modified. Now it refers to Bloom et al. (2013) only as to an example of a paper dealing with technological spillovers.*

4. I am not convinced by a comment on page 15 that suggests that the discount rate in constructing R&D capital stock is irrelevant, as it becomes a constant after the log-log transformation. Intuitively, the discount rate affects the time composition of the R&D stock, i.e. the relative importance of more recent and more distant R&D expenditure for current economic performance. To see this, expand equation 2.1 for all periods, using 2.2 for the initial period. [a minor modification required or discussion to be added]

   Author: *I have added the discussion in a footnote. Just to summarize my argumentation, the choice of depreciation rate affects the estimation in two ways. First, it affects the value of the first imputed R&D stock. This indeed influences the estimation but only through the first imputed value. Its different value is controlled for by the log-log transformation and fixed effects at other points in time. Second, the subsequent R&D stocks are multiplied by the coefficient depending on the depreciation rate. However, these different coefficients are also stable over time and so are also controlled by the log-log transformation and fixed effects. The choice of depreciation rate affects the estimation only through the different imputed R&D stock at time 0.*

5. The paper does not make clear the level of industry detail in the input-output table used. Does the I-O table cover 120 industries? It is not very common to have such detailed input-output tables available (e.g. tables available on the web of the Czech Statistical Office cover 82 industries). [a clarification required]

   Author: *The Czech Statistical Office provides Input-Output table with the granularity of 81 industries. Those industries were carefully mapped to the used data set. Since both are based on NACE2, such a mapping is consistent. I have added this clarification to the manuscript.*

6. In a panel regression with fixed effects, it is customary to cluster at the level of panel units, i.e. industries in this case. Has clustering been used? The paper only mentions "robust standard errors". [a clarification required]

   Author: *The estimation employs clustering at the industry level as it is implemented in the Sandwich R package.*

7. One important type of spillovers not discussed in the paper is cross-border spillovers. These naturally cannot be analysed with data for one country. What would be needed to analyze these? [discussion to be added]

   Author: *I have added a comprehensive footnote discussing this issue in the concluding section of Chapter 2.*

A.3.2 Chapter 3: Who Benefits from Global Value Chain Participation? Does Functional Specialization Matter?

The second paper examines whether participation in global value chains (GVCs) increases value added in a particular country-industry pair. Like the first paper, it explores a particular source of knowledge with a potential to increase productivity in an industry, using industry-level data and linear regressions with unit and time fixed effects. It, however, uses a different data source and, importantly, rather than focusing on the Czech Republic, it studies datacovering about 40 countries.

Overall evaluation

The paper again builds on a well-established literature and the contribution consists mainly of examining the heterogeneity of the effects along previously unexplored dimensions. In particular, it examines

1. how the effects of GVC participation depend on specialisation in different business functions (R&D, fabrication, marketing and management),
2. how they effect on whether value chains connect the same industry (in different countries) or different industries, and
3. how they depend on the level of development of a given economy.

Comments

1. Although the foreign share of value added is assumed to enter the productivity term of the production function (3.4) and the estimation controls for labour and capital (similar to the first paper), the author talks about effects on value-added, not productivity, throughout the paper. This seems to be a common practice within the GVC literature, but it seems somewhat strange to me. An additional discussion of this choice would be appreciated. [discussion to be added]

   Author: *I believe this to be a semantic issue. There are two empirical approaches to relating phenomena such as GVC participation to productivity. The first approach is to make the phenomenon a part of a production function. We then look for a relationship between the phenomenon and value-added in a more complex system. The second approach is to estimate productivity in terms of TFP and then relate this outcome variable to any phenomena we might be interested in. Both of these approaches are similar. The strategy resembles two-stage least-squares (2SLS) regression, so under certain conditions, they are even equivalent. Yet, as with 2SLS, we tend to use the same language when we interpret the results. I believe both interpretations are permissible, so I used the one which seems to be widely used in the literature and is versatile enough also to describe also value-added resulting from GVC hierarchy. For clarification, I have added a footnote dedicated to this problem in the introduction section of Chapter 3.*

2. The production function estimates show strangely large capital elasticities (around 0.57) and unusually small labour elasticities (around 0.25). This is at odds not only with basically all production function estimates in the

literature, which consistently show much larger labour coefficients, but also with the estimates in Chapter 2. I suspect that either capital and labour have labels accidentally swapped in the results tables, or there is something wrong with the definition of the variables (see also the following points). [a clarification to be added, discussion to be added or analysis to be checked]

Author: *I have checked the analysis and the coefficients have been indeed swapped. Thank you for pointing it out, I have corrected the results in the manuscript.*

3. Relatedly, the summary statistics for the labour variable (Table 3.1) are strange. If I read them correctly, they indicate that in an average country-industry in the sample there are 384 full-time-equivalent workers and a value added of 351 USD millions. That corresponds to approximately 1 USD million of value added per worker, which is implausibly large, especially given that the sample includes some less developed economies. [a clarification to be added, discussion to be added or analysis to be checked]

   Author: *There is a mistake in Table 3.1. The variable Labor is measured in FTE thousands. I have corrected this mistake.*

4. The data distinguish between 4 business functions (R&D, fabrication, marketing and management), but the estimated regressions tend to focus only on the first three. This is makes perfect sense for the own-industry business function shares (e.g. in Table 3.4), where management serves as the omitted category, but it is strange when distinguishing between business function composition of the foreign value added, as in Table 3.5. The specifications in Table 3.5 do not contain an uninteracted foreign share of value added, so management function in foreign value added is missing in the Table, and, as a result, regressions in Table 3.5 are not a generalized version of those in Table 3.4. [a minor modification in the analysis may be required]

   Author: *The general FVAS measure is indeed missing in the analysis. I have rerun the estimations with the general FVAS and the results change only cosmetically.*

A.3.3 Chapter 4: Heterogeneity of GVC Participation Effects and Its Catalysts

The third paper creates a bridge between the previous two papers, by bringing together the effects of R&D and GVC participation, together with foreign direct investment (FDI), which is interpreted by the paper as strongly hierarchical type of GVC structure. This allows studying the role that absorptive capacity plays in allowing industries to benefit from participation in GVCs. The paper focuses on the Czech Republic, but uses the inter-country input-output data used also in the second paper.

Overall evaluation

Like the other papers in the dissertation, the paper builds on a well-established literature and uses appropriate methods to study relevant question. The contribution consists of bringing together multiple factors and studying their interactions, but it is somewhat harder to discern the contribution to the literature, as it is less explicitly explained (although not necessarily weaker) than in the other two papers.

Comments

1. The contribution of this paper beyond and above existing literature is less clearly explained in this paper than in the other two. It might be made more explicit. [additional discussion?]

   Author: *I have expanded on the introduction section of Chapter 4. I have shown how the paper bridges two strands of literature and by admitting certain shortcomings related to industry-level data, I have suggested a direction for future research.*

2. Given that the main sources of data are international (WIOD, Eurostat), it is not clear why the paper restricts attention to the Czech Republic (this is not the case with the first paper, which takes advantage of a relatively disaggregated industrial structure that is available for Czechia but not internationally). [a short discussion of the choice would be useful]

   Author: *This is because of the introduction of FDI to the analysis. To my knowledge, harmonized data on FDI with the required granularity was not available. Using data as reported by distinct institutions (central banks, statistical offices, etc.) would make the analysis prone to bias due to data inconsistency between reporting countries. I believe an anal-*

ysis with fewer sectors but more countries would be a natural extension of work initiated by this paper.

3. Similar to the second paper, the summary statistics (Table 4.1) strangely imply a value added labour productivity in an average industry of about 20 millions CZK per full-time-equivalent worker. [a clarification to be added, discussion to be added or analysis to be checked]

   Author: *As with the previous chapter, the table should refer to "FTE thousands", and now it does.*

4. The paragraph below equation 4.6 talks about "R&D intensity:, but I suppose this should be "R&D stock". [please fix]

   Author: *It is supposed to be R&D stock. The correction has been made.*

5. Page 55 starts from the middle of a sentence. [please fix]

   Author: *The issue of wrong copy-paste has been fixed.*

6. The author suggests that the negative estimate for outward FDI stock could be related to outsourcing core activities (such as assembly) while keeping other activities. He then suggests that the kept activities might be recorded in other industries in the data, and the negative effect is, thus, due to limitation of the data. But, as I outlined earlier, the estimates should be thought of as productivity, because they control for capital and labour. If some activities are recorded under other industries, this should be the case not only for value added but also for capital and labour, so it is not clear why it should lead to lower productivity. Instead, a simpler, even though somewhat counter-intuitive, explanation is that high-productivity activities are being outsourced while some lower-productivity activities are kept in-house. [to consider]

   Author: *The point you are raising is correct. I have rewritten this conclusion and incorporated your arguments. Thank you!*

A.3.4 Minor comments on the language

1. Throughout the dissertation, Ăş and Ă in the text here and there. There must be some issue with the type-setting software used and it should be fixed. [fix typo]

Author: *I have gone through the manuscript and made sure quotes are printed correctly into a pdf.*

2. There is something wrong with the first full paragraph on page 5 in the introduction, as it twice states that there are positive direct effects of privately funded R&D. [fix text]

   Author: *I have corrected this mistake.*

3. There are a few typos, it would be good to put the thesis through a spell check once again before publication.

   Author: *I have gone through the manuscript once again and hopefully corrected all the remaining typos.*

4. In English, unlike Czech, there are no commas before "that" linking phrases.

   Author: *The dangling commas have been deleted.*