How Do Patents Shape Global Value Chains?

International and Domestic Patenting and Value-Added Trade

January 2019

Nikolas J. Zolas, Center for Economic Studies, United States Census Bureau

nikolas.j.zolas@census.gov

Travis J. Lybbert, Agricultural & Resource Economics, University of California, Davis;

tlybbert@ucdavis.edu[1]

Abstract

Intellectual property plays an important role in the global economy through its impact on technology diffusion, knowledge transfer and competition. As production has become fragmented into coordinated processes that span the globe, the role of patents has evolved. Patents can transmit technical knowledge and facilitate upstream and downstream licensing arrangements, thereby increasing the flow of intermediate and final goods and catalyzing knowledge spillovers across sectors and regions. We exploit an algorithmic concordance that links patents to industry and product classifications to estimate how patents affect the organization and structure of Global Value Chains (GVCs). Using the World-Input Output Database as the basis for various GVC measures, we find that increased international patenting inflows are associated with greater value-added production, but that this positive effect is driven entirely by industries in high-income countries. We also find some evidence of heterogeneity in these effects by region and sector-specific R&D intensity. We conclude with discussion of important limitations of this exploratory analysis and implications for future research.

JEL Codes: F12, F14, O30

Keywords: Intellectual Property, Patents, Global Value Chains, Value-added trade, Upstreamness.

1 Any opinions and conclusions expressed herein are those of the authors and do not necessarily represent the views of the U.S. Census Bureau. We thank participants at the World Bank and Peterson Institute Conference on Global Value Chains, the 2015 Patent Statistics for Decision Makers Conference, the WTO Seminar on IP and Knowledge Flows in a Digital Era, and seminar participants at UC Berkeley, UC Davis, the Max Planck Institute, and Inter-American Development Bank (IADB). We also thank Russell Hillberry, Dietmar Harhoff, Andy Toole, and Mingzhi Xu for valuable feedback and suggestions. All remaining errors are our own.

1. Introduction

Potential linkages between patents and international trade motivated the negotiation of the Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement as part of the Uruguay Round of the GATT in 1994. Since the agreement, numerous studies have analyzed the role of patenting institutions on the composition and quantity of trade flows. These findings suggest that increased use of patents and other forms of intellectual property (IP) have stimulated imports in knowledge-intensive and high-tech goods for several countries (Braga and Fink 1999; Vichyanond 2009; Awokuse and Yin 2010; Ivus 2010). The close relationship between patenting, investment and trade partly reflects similarities in the costs and benefits of each activity and how they shape technology transfer.

Coe and Helpman (1995) demonstrate the important effects of foreign R&D on domestic productivity, highlighting the contributions of international knowledge spillovers, in which both patents and trade figure prominently. However, the precise nature of the relationship between patents and trade is not fully understood. In modeling international patent flows, economists have traditionally relied on "gravity"-type models, where flows are determined by the relative size (GDP) of countries, as well as distance and other country-specific variables (see Slama 1981; Bosworth 1983; Harhoff et al. 2007; Eaton et al. 2004; Zolas 2014). Relatively little is known about the dynamics, spatial and industry patterns, and economic implications of this important relationship between patenting and the structure of global trade. This gap in our understanding stems principally from our inability – until recently – to connect patenting and trade at a high enough resolution to account for substantial industry-level heterogeneity.

While our understanding of how the knowledge embedded within patents gets transferred abroad is still somewhat rudimentary, the production processes generated, in part, from this knowledge have undergone a radical shift. Advances in communication and transportation technology, along with a reduction in trade barriers, have enabled what Richard Baldwin calls the "great unbundling," with different stages of the production chain sliced into tinier fragments and spread more broadly around the world (Baldwin 2006). At the most basic level, these production processes begin with raw materials being converted into basic inputs, which are then combined with more and more intermediate inputs until the final good is assembled. However, at a deeper level, the process is much more complicated and entails product, input and knowledge flows moving back and forth, horizontally and vertically. Numerous models have been proposed that help explain the production and ownership decisions of these processes such as Costinot et al. (2013) and Antras and Chor (2013), along with the impact of these value chains on trade flows (Baldwin and Venables 2012; Yi 2003; Harms, Lorz and Urban 2012). The findings point to various determinants of value chain composition including the complexity of the process as captured by the number of distinct production stages and the position of the product within the supply chain relative to the final retail stage ("*Upstreamness*"), which importantly shape both the volume of trade flows and global income distribution.

In this chapter, we explore the relationship between new quantitative measures of GVCs and patents across industries and countries.[2] We use the algorithmic matching techniques proposed by Lybbert and Zolas (2014) to link the technology classes of patent flows from the PATSTAT database with the industry codes found in the input-output tables from the World Input-Output Database (WIOD). In doing so, we can test the impact of patent flows on different features of GVCs. Because the GVC measures we use are especially relevant to contemporary global supply chains, they provide a much better basis for testing the relationship between trade and patents than traditional trade measures such as gross exports and imports.

Given the scope and complexity of this topic, our approach is intentionally modest and intends to provide initial exploratory evidence related to broader efforts to understand international innovation systems (e.g., Fromhold-Eisebith, 2007). As an exploratory exercise, we face a number of data limitations. We cannot observe in our data the complex structure and ownership of multinational firms and can only differentiate patents by industry and not by use or product versus process. Although the patterns we unveil are broadly relevant to current and future value chains, we necessarily rely on data from the past few decades and therefore cannot empirically test for how more recent innovations in the current digital era alter these patent-GVC relationships. Finally, we do not have pure exogenous variation in patent flows with which to identify the pure causal impact of patents on GVCs and instead lean on a weaker, predictive causality strategy. Despite these limitations, this exploratory analysis provides some intriguing initial insights that have both policy and research relevance.

Using country-industries (a given industry in a specific country) as our unit of analysis, we show that increased patent inflows and outflows from abroad are associated with increased value-added production in the form of exports. Through disaggregated analysis, we find that this effect is driven by impacts in high-income countries. Industries in middle-income countries, by contrast, experience greater production fragmentation as a result of international patent flows. We find some evidence of additional heterogeneity in these effects by region and sector. We detect relationships between patents and changes in the structure of GVCs as captured by other measures as well. While these analyses do not test whether patent flows

[2] For a more extensive and more technical version of the analysis in this chapter, we refer readers to Lybbert et al. (2019).

benefit country-industries through their effect on GVCs because our focus is on changes in GVC measures rather than total production value, they do suggest a direct link between patent policies and the structure and functioning of value chains.

2. Conceptual Framework: The Structure of GVCs and Patent Flows

The “great unbundling” (Baldwin 2006) has dramatically changed the structure and management of production across most sectors and countries and altered the flow of both tangible and intangible assets across borders. The complex GVCs that have emerged in recent decades present both a challenge and an opportunity for firms seeking to upgrade their engagement, position and profitability in these chains. Competitive pressures and ever-evolving technological frontiers in this digital era will continue to shape GVCs. As they navigate these challenges and opportunities, firms face an array of strategic and tactical considerations, including incentives shaped by regulatory and legal systems (see Neubig & Wunsch-Vincent in this volume for a discussion of incentives arising from tax law). Since firms in a given industry face many common forces and incentives, these firm-level decisions map into industry-level GVC patterns that are quite distinct.

A vast academic, policy and practitioner literature has emerged alongside these rapidly evolving GVCs. This work, now spanning decades, provides a rich conceptual basis for understanding GVCs, empirical GVC measures and analysis of their functioning, performance and effects, and detailed policy recommendations for countries and industries seeking to upgrade their position in GVCs. While this work demonstrates the long reach of GVCs (i.e., firms with no link – direct or indirect – to GVCs are increasingly rare), it also suggests the particularly prominent role of GVCs in developing countries because fragmented production stages can create more manageable opportunities and facilitate initial entry. Consequently, value-added trade contributes significantly more to GDP in developing countries (30% on average) than in developed countries (18% on average) (UNCTAD 2013 report).

Efforts aimed at upgrading and enhancing value-added trade are particularly relevant to the analysis in this chapter. A standard progression of upgrading begins with processes (e.g., improving manufacturing efficiency) then shifts to products (e.g., product innovation, quality improvements), and culminates with functional upgrading (e.g., innovation from upstream design stages to downstream distribution stages). While firm-level decisions are central to any progression of upgrading, measures of GVC performance tend to focus more on aggregate input-output tables because of data available. These tables, though coarse, have the advantage of being accessible and have consequently become the basis for a family of GVC measures. We use three such measures to capture for each country-industry (i.e., a given industry in given country) its value-added exports as a share of total exports (VAX Ratio, *VAX* hereafter), the complexity of production based on the number of distinct stages in the GVC (*NStages*), and its position relative to the final retail stage (*Upstreamness*). Increases in the *VAX* signal effective upgrading as the value-added composition of trade is higher, whereas decreases in the *VAX* signals increased production fragmentation (i.e., lower value-added contributions by a given country-industry). While upgrading and enhancing the share of value-added contributed by a country-industry is a popular industrial strategy, this does not imply that a declining *VAX* signals unfavorable economic conditions. To the contrary, integration into the global economy can simultaneously lower the *VAX* and increase total value creation by dramatically expanding total exports. Upgrading is more difficult to discern in the *NStages* and *Upstreamness* measures given the familiar non-linearities of the "smile curve" that suggests that value-added is highest in upstream and downstream production stages and lowest in the middle stages. It is important to note that an increase in any of these GVC measures would indicate whether the GVC is undergoing increased complexity (from adding additional production stages) or moving further downstream from the final good. Either way, an increase is not necessarily good or bad for the underlying country-industry as the overall effect is a function of many other factors. In the global economy, a country-industry can prosper with either a rising or declining *VAX* as long as total productivity – the translation of inputs into value – is increasing.

In this chapter, we explore the empirical relationship between patents and GVCs at the country-industry level as captured by these measures. We estimate elasticities for each measure with respect to patents flowing - both domestically and internationally - to and from a given country-industry. These elasticities assess how sensitive the GVC measures are to changes in patent flows. While this is novel as an empirical exploration, others have probed this relationship from different angles. For example, WIPO (2017b) documents the importance of intellectual property more broadly defined ("intangible capital") in contemporary GVCs. By attributing value-added production in GVCs to tangible and intangible capital and labor, the report shows that about a third of production value is due to intangible capital, which is more than the value attributable to tangible capital. Building on the work of Gereffi et al. (2005), the report describes how the nature of knowledge and information flows required by GVCs – especially their complexity and codification in transferrable packets – along with the capabilities of the firms involved shape the organizational and governance structure that emerges in the GVC.

While our empirical analysis cannot capture either the richness of GVC governance or the full breadth of intangible capital (we restrict our focus to patents), the conceptual underpinnings of ownership along GVCs are nonetheless relevant. Consider what models of property rights in production processes along value chains imply about how firm-level incentives and management may shape the GVC measures we use.

Antras and Chor (2013) model production ownership by a parent firm in production chains and offer conditions for patenting abroad. Patenting denotes ownership of the product or process within the production chain, ensuring that the technical knowledge embedded within the product or process flows to the subsidiary through licensing or ownership. In this framework, a firm patents to ensure that the production process is completed according to the exact specification embedded within the patent. More generally, patenting in the intended production location provides the parent firm with an ownership stake in production inputs, processes or outputs. Even when this patent-based ownership stake falls short of a subsidiary relationship, it can serve to reduce contractual frictions associated with fragmented and outsourced production. Thus, patents in the Antras and Chor (2013) framework facilitate knowledge transfer and reduce contractual frictions. When a firm patents in a jurisdiction with the intent of producing in that location, patenting thereby leads to potentially higher value-added production in this target destination. Beyond the Antras and Chor model, however, if we allow for non-productive patenting motives (e.g., defensive patenting to block competitors' access to inputs, processes or markets), the relationship between patenting and value-added production is more complex and may push in the opposite direction.

Our analysis aggregates firm-level patenting and GVC decisions to the country-industry level. While this complicates the direct application of firm-level models to our analysis, many of the forces and incentives faced by firms in a given country and industry share common features. This translates, albeit imperfectly, firm-level decisions into distinct country-industry GVC patterns. The relationship between patent flows and GVC measures at the country-industry level reflects the average firm-level relationship, which – according to the firm's patenting intent – can be either positive as suggested by the Antras and Chor model or negative as suggested by non-productive motives such as defensive patenting. Thus, how (or even whether) patents shape GVCs at the country-industry level is unclear *a priori*. Our empirical exploration aims to shed light on this relationship.

3. Data and Construction of Global Value Chain Measures

In this section, we describe the measures we use to understand the relationship between patenting and GVCs at country-industry level. GVCs are often complex, intricate and vary by firm and product. Country-industry measures of GVCs cannot capture all this richness and resolution, but are nonetheless useful as coarse measures of certain components of value chains. For our analysis, we rely on three different GVC measures that have been documented in the literature, namely: the *VAX* – the ratio of value-added production to total value of exports; *NStages* – the number of stages in the production process; and *Upstreamness* –the mean-distance (in production stages) from the final good. We construct each of these measures from the same source data: the World Input-Output Database (WIOD) as described in Timmer et al. (2015), which covers 42 countries and 35 industries and yields a 1435 × 1435 input-output matrix for each year from 1995-2011. The WIOD sample contains 27 EU countries and 15 other major countries. Of the 35 industries, 14 are in manufacturing.

Our methodology for constructing the value-added trade data follows the multi-country, multi-product methodology first established in Johnson & Noguera (2012) and used in their subsequent working paper (Johnson & Noguera 2017). Our methodology for the number of production stages, *NStages*, and *Upstreamness* measures come from Fally (2012) and Antras et al. (2012). We merge these GVC measures at the country-industry-year level with patent grant data from PATSTAT and control variables from other data sources as described below. For a detailed description of our application of these methods to construct these measures, see the more technical analysis in Lybbert et al. (2019). The following sub-sections provide a brief summary of the construction and intuition of each of the measures. Figure 1 heuristically depicts the construction of the final dataset we use in this analysis.

3.1 Value-Added Trade: VAX

The process proposed by Johnson & Noguera (2012) for constructing the *VAX* measure uses input-output tables and assumes a circular process of production where inputs and outputs are continuously transferred from one country-industry to another, implying an infinite number of production stages. To simplify the process, they assume a sequential two-stage production process where intermediate goods are only used to produce final goods (as opposed to other intermediate goods). The VAX ratio consists of separate components that further break down the value-chain, such as the share of intermediate goods shipped elsewhere and then shipped back, and the share of intermediate goods that are consumed in a third country as a final good. While we do not break down the VAX ratio into each of the components, we want to point out that movements in the VAX ratio are going to be driven primarily by differences in the share of intermediate goods produced elsewhere.[3]

Between 1995 and 2011, the aggregate *VAX* across our sample of countries declined by 5.6%, indicating increased fragmentation as the share of value-added exports over gross exports has fallen. This decrease is

[3] Using the terminology in Johnson and Noguera (2012), movements in the VAX will mostly be driven by "reflected" exports and the gap between "absorbed" exports and "net absorbed"

mostly being driven by the fact that gross export flows for these countries have outpaced value-added export flows. Value-added exports have grown by 177% over this period, while gross exports have increased by 194%. Meanwhile, patent flows over this time period for the same set of countries has increased by 93%.[4]

As a preliminary perspective on the unconditional relationship between *VAX* and international patent flows see Figure 2 (left). In this figure, we plot annual *VAX* measures and patent flows by sector over the period 1995-2011.[5] We provide a trend line for each sector group to indicate the (unconditional) time trend in this relationship. Although purely descriptive, the patterns in this plot indicate a negative association between patents and *VAX* for nearly all sectors (the exception is "Electrical & Machinery") – with total international patent grants increasing and *VAX* decreasing (i.e., production fragmentation increasing) over this period. In the empirical analysis below, we move beyond these unconditional, descriptive patterns and towards estimated effects with a degree of causal inference.

3.2 Production Stages: *NStages*

Our empirical analysis captures both inter- and intra-industry flows, and one measure of interest for global value chains are the number of production stages required to generate the final product. Holding aggregate value constant, more production stages for the same product would indicate less value-added per stage. To determine the number of production stages, we implement the methodology introduced by Fally (2012), who develops a measure for the weighted-average number of locations involved sequentially in the production of a good. The measure is constructed on the assumption of sequential production.

We plot the unconditional relationship between international patents and *NStages* broken out by sector in Figure 2 (middle). Between 1995 and 2011, we find that the number of production stages for each country-industry in our sample has declined on average by roughly 7.5% indicating increased consolidation in the

[4] Another takeaway is that the movements in the VAX ratio differ from the results found in Johnson and Noguera. This is due to a variety of reasons having to do with different data sources being used, different countries and different industries, as well as a longer time horizon of the data. In Johnson and Noguera (2017), the authors have a brief discussion in the footnotes discussing how the WIOD database fails to capture some important changes to the VAX ratios over the time period and how their study relies on the variability accrued over a four-decade long period. Besides the difference in time horizon, between the John and Noguera data (30 years versus 16 years in the WIOD), Johnson and Noguera also pay particular attention to Asian countries which underwent rapid industrialization during their time frame, while the WIOD focuses mainly on European countries.

[5] The R&D intensity of sectors is based on the OECD R&D intensity taxonomy (Galindo-Rueda and Verger 2016). For the same plot disaggregated by sector rather than sector R&D intensity groups, see the Appendix.

production process over this time period. We see similar declines and movements across all sectors with "Petroleum & Chemicals" seeing the largest decline.

3.3 Distance from Final Good: *Upstreamness*

As a final GVC measure, we use the average distance from the final product for each country-industry. As the 2017 WIPO report (WIPO 2017) demonstrates, value-added follows a U-shaped "smile curve" with respect to distance from the final good: processes further from and closer to the final good tend to have higher value-added content. Our measure of *Upstreamness*, which is based on Antras et. al. (2012),[6] increases as a given country-industry moves to more upstream positions in its value chain. The steps to develop this measure are somewhat similar to the steps undertaken in the metric of *NStages*, as it is a recursive process that captures the mean distance of each within-country intermediate input from the final good by tabulating the intermediate input shares of each country-industry.

Between 1995 and 2011, the average *Upstreamness* for all of the country-industries in the WIOD declined by 2.2%, indicating that more production was happening further downstream. Figure 2 (right) plots the relationship between patents and measures of *Upstreamness* by sector and finds some variability in this unconditional relationship. Most sectors have similar responses to international patents (a steady decline), but "Textiles" sees an increase in *Upstreamness* and "Food & Beverages" has almost zero change.

The figures indicate that the average number of production stages and the average distance of each country-industry from the final good has been declining over this period. Since the *VAX* also declined over these years, these overall changes suggest that the increased production fragmentation (declining *VAX*) has – on average – taken a specific form. Specifically, this pattern could be explained either by increased fragmentation in upstream stages that is partly offset by the emergence of fewer and higher-value stages further downstream (hence, declining *NStages* and *Upstreamness*). Or this result could be an indication that the upstream production process in the destination country is consolidating and producing less value-added than before. Our econometric analysis below seeks to control for the various confounding factors that complicate meaningful interpretation of these unconditional correlations.

3.4 Patent & Other Data

[6] This measure is very similar to the measure of *downstreamness*, which is separately identified in Antras and Chor (2013) and Fally (2012).

As our measure of patent flows, we use the number of granted patents in a given year and associated with a given industry. To distinguish between domestic and international patents, we define the origin of the patent as the inventor's country as listed on the patent application.[7] Thus, international patent inflows represent the number of patents granted by one country to foreign inventors.[8] International patent outflows represent the number of patents granted in a foreign country to home country inventors. We construct aggregate unilateral versions of these patent flow measures along with domestic patent grants using the PATSTAT database available from the European Patent Office (EPO) with supplementary data provided by the World Intellectual Property Organization (WIPO). In order to associate a given patent with a given industry, we must concord the classification system used for patents into the industry classifications used in the WIOD database. The industries for the WIOD databases are organized by ISIC Rev.3, with most groupings occurring at the 2-digit level. The database combines the 60+ two-digit level ISIC classes into more aggregate classes to fit the 35 industry groups of the WIOD. To concord the patent data organized by International Patent Classification (IPC) to the industry data organized by ISIC, we use the probabilistic concordance developed in Lybbert & Zolas (2014).

For control variables, we use GDP and GDP per capita measures from the World Bank, trade proxies, such as distance, border dummies, language dummies and colonial history from CEPII. To explore more directly heterogeneity by income level, we disaggregate our analysis by high- and middle-income countries as defined by the World Bank.[9]

4. Value-Added Trade & Patents: Analysis & Results

Our exploration begins with an aggregate look at the impact of patent flows on a country-industry's value-added trade. This analysis is at the country-industry level and considers both domestic and international

---

[7] In cases where multiple inventor countries are listed on the patent, we take the modal inventor country as the origin. We randomly assign inventor country in cases where two or more countries appear in this field with equal frequency. Although PATSTAT does not list the country of origin for all inventors, fewer than 5% of the patents in our sample (i.e., to and from countries represented in WIOD) are missing this information. We see no statistical differences in technological field (IPC) between patents with and without inventor country of origin.

[8] Given our focus in this analysis on patent grants in a given country-industry, it is not necessary to account for patent families that relate to a common invention. There are surely other empirical angles one might take to addressing questions about patents and GVCs that would leverage patent family information and structure, but that is beyond the scope of this work.

[9] These classifications are available at https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups (accessed 27 September 2018). Note that the WIOD data does not include low-income countries, for which patent statistics are also sparse. Hence, our income comparison is between high- and middle-income categories.

patents. As we describe our empirical approach, recall from above that our GVC measures relate specifically to a given industry in a given country and, as a data-weighted average of firm behavior in a given country-industry, captures aggregate value chain patterns.

4.1 Estimation Approach

We first evaluate how international patent inflows, international patent outflows and domestic patents are associated with changes in the *VAX*. We then estimate the similar specifications to test the relationship between these patent flows and *NStages* and *Upstreamness*. Our specification in each case produces elasticities of these measures with respect to changes in patent flows of different kinds (e.g., percent change in the *VAX* for every one percent change in international patent inflows). Specifically, we estimate these elasticities using the following specification:

$$\ln "GVC"_{ikt} = \alpha + \beta_{in}\ln PAT_{ikt}^{in} + \beta_{out}\ln PAT_{ikt}^{out} + \beta_{dom}\ln PAT_{ikt}^{dom} + X_{it} + \delta_{ik} + \delta_t + \epsilon_{ikt} \quad (1)$$

where $"GVC"_{ikt}$ is one of our three GVC measures for industry *i* and country *k* in year *t*; PAT_{ikt}^{in} and PAT_{ikt}^{out} are international patent inflows and outflows, respectively; X_{it} is a vector of country-specific control variables (GDP, GDP per capita and WTO membership); δ_{ik} denotes industry-country fixed effects, and δ_t denotes year fixed effects. With these fixed effects included, our estimated patent flow elasticities (β_{in}, β_{out}, β_{dom}) capture variation *within* country-industry (i.e., controlling for average differences in GVC measures by country-industry) accounting for the overall yearly average level of these measures.

In addition to estimating this equation for all countries in our sample, we also estimate it separately for high-income and middle-income countries in order to allow these elasticities to vary by level of economic development as an important dimension of heterogeneity. We explore two additional dimensions of heterogeneity in the relationship between patent flows and GVCs by estimating this specification separately by sector and region of the world.

In this empirical exploration, we seek to understand whether and how patent flows and GVC measures are associated with each other. Because we do not exploit pure exogenous variation in patent flows, we caution against strict causal interpretations of our estimated elasticities. We argue, however, that a weaker form of causality (in addition to simple statistical associations) may be justified. The choice of a given firm to apply for patent protection in a given jurisdiction is clearly endogenous as it is a function of the firm’s perceptions of future market conditions, including factors that likely influence our GVC measures. Patent grants, on the other hand, lag behind initial applications by a few years on average. Moreover, the actual lag length (and whether the patent is ultimately granted at all) is subject to a degree of random variation, which introduces exogenous variation into patent grants that is not present in endogenous patent applications.[10] By using patent grants as our measure of patent flows, we avoid in part the endogeneity arising from strategic patent application decisions. On this basis, our patent flow elasticities capture a form of "Granger causality" (i.e., predictive causality): If patent grants in a given country-industry are associated with changes in the GVC position of that country-industry even though the patent application decision randomly pre-dated the grant by up to several years, we can conclude that patent grants are not only *associated* with GVC position, but that *predictive causality* likely runs from patent flows to GVC position. Because we match patents to our GVC measures based on their grant date, any such effect is essentially contemporaneous, which implies that our results capture the short-term relationship between patent flows and GVCs rather than a longer-run dynamic and interdependent relationship between the two.

Our interpretation of the coefficients are relatively straightforward. In the case of the *VAX*, a decrease indicates that relatively less value-added production is occurring in country *i* and industry *j*, which suggests that production is becoming more fragmented in value terms. Hence, a negative β coefficient in equation (1) – that is, a negative patent-GVC elasticity – imply that an increase in the corresponding patent flow is associated with greater dispersion of the production process across GVCs. For *NStages* and *Upstreamness*, respectively, a positive β coefficient suggests that patent flows lead to an expansion of production stages, which is consistent with increased complexity, and to the country-industry shifting its production position in the GVC downstream (i.e., further away from the final good).

4.1 Results

To facilitate the presentation of results, we show estimated elasticities graphically and report the associated numeric estimates in full tables of results in the appendix. In Figure 3, we show the estimated elasticities for *VAX*, *NStages* and *Upstreamness* with respect to patents flowing from different sources. The estimated elasticity for "All" country-industries in the data provide the main results, which we then disaggregate along the dimensions of income (high- vs. middle-income countries), sector categories, and geographic regions

[10] Patent examination lags and outcomes in the U.S., Japan and Europe have been analyzed in some detail, but little systematic work has been done to characterize patent examination in other offices. The data that is available suggest significant heterogeneity across countries and sectors (e.g., WIPO 2017a). While some of this variation can be explained by observable factors such as technological class and inventor origin (e.g., Harhoff and Wagner 2009), much of the variation in examination delays is stochastic (i.e., unexplained).

of the world. These results suggest several interesting patterns in the relationship between patents and GVCs.

Consider first the *VAX* results. Overall, we see that the *VAX* for a given country-industry increases with both inflows and outflows of international patents to/from that country-industry. These movements are mostly small in magnitude on a year-to-year basis.[11] This is unsurprising given the limited cumulative movements in the *VAX* over this period (-5.6% overall or -0.35% per year on average) relative to the changes in patent output. The overall effect of domestic patents is more modest, but still significantly positive at the 5% level. Interestingly, high- and middle-income countries experience different effects between patents and GVCs. For middle-income countries, international patents flowing into and out of country-industries *reduce* the *VAX* and lead to more fragmentation for middle-income countries, while domestic patenting related to a given country-industry is associated with increase in the *VAX*. This suggests that while domestic patenting enables country-industries to enhance their value-added position in GVCs, international patenting (patent inflows) fragments their value-added production. It is important to note, however, that a declining *VAX* does not imply that the country-industry is not benefiting from GVCs – only that its value-added share of total exports is relatively declining. Income per capita and employment gains and other improvements can also accompany the structural transformations that associated with production fragmentation captured by a declining *VAX*.

The other two panels in Figure 3 indicate similarly heterogeneous results for high- middle-income countries with elasticities for *NStages* and *Upstreamness*. The *NStages* elasticities are statistically zero, except for middle-income countries. International patent inflows increase the number of production stages in country-industries in these middle-income countries, while the estimated elasticity with respect to outflows is strongly negative. Elasticities of *Upstreamness* also suggest some stark differences between high- and middle-income countries. Whereas this elasticity for patent inflows is negative for high-income countries, it is positive for middle-income countries. For patent outflows, all three elasticities are negative, with the middle-income estimate significantly larger in magnitude. Middle-income countries see no relationship between the *Upstreamness* of their country-industries and domestic patents, but high-income countries see a positive relationship.

---

[11] Given a mean growth of international patents of 93.5% over the period 1995 to 2011, our baseline coefficient suggests that the cumulative impact of patent inflows added an additional 0.10 percentage points to the VAX ratio, while the cumulative impact of patent outflows contributed an additional 0.18 percentage points to the VAX ratio .

To complement the breakdown by income level, we explore heterogeneity in the patent-GVC relationship by sector and by region of the world in Figures 4 and 5. While there is some variation across sector in terms of magnitude and significance, most of the sectors share similar signs for patent inflows and domestic patents. While the confidence intervals on these coefficients often overlap, indicating that there is no statistically measureable difference by sector, there are some pronounced exceptions to this pattern – particularly with patent outflows. The coefficients on patent outflows for "transportation" manufacturing differs significantly from the other sectors across all GVC outcomes with regards to patent outflows. We see a lower VAX ratio (greater fragmentation), more stages of production and further upstream production for "transportation" manufactured goods when patents flow out of a given country-industry to the broader GVC. This seems to be consistent with the "just in time" production system that was famously developed by Toyota, which spread throughout manufacturing sectors in the 1980s and 1990s.

We find even more pronounced variation in the effects of patent flows on GVC measures by region (Figure 5). Since the variation in estimated coefficients by region reflects all regional differences – including structural factors, income levels, policy environments, etc. – we cannot attribute different coefficients to a specific or simple determinant, but there is, nonetheless, some intriguing patterns in Figure 5. The patent flow elasticities for European countries tends to be relatively modest in magnitude, but also precisely estimated (i.e., smaller confidence intervals on the coefficients).[12] The estimated elasticities for the Americas and Asia are more likely to share the same sign than other regions, although they are often significantly different in magnitude. Patent inflows increase production fragmentation (decrease the VAX) in the Americas and Asia, but decrease fragmentation in Europe. The pattern of regional patent elasticities is qualitatively very similar for *NStages* and *Upstreamness*, with patent inflows increasing both measures in Asia and the Americas and decreasing both in Europe and Oceania. Domestic patents have the opposite effect across these regions. Although more a first step than the final word, this considerable regional variation in the effect of patents on GVCs is nonetheless intriguing – and merits future attention.

5. Discussion & Conclusion

The "great unbundling" that has played out over the past several decades has created complex GVCs that span the planet and raises a host of interesting and important questions. In this chapter, we tackle one such question – and a relatively narrow one at that: What role do patents play in the organization and structure

[12] More generally, the more heterogeneous a region is the larger is its confidence interval.

of GVCs? Our empirical analysis aimed at addressing this question is distinctly exploratory in nature. While the results are much more a "first step" than the "last word," they nonetheless offer some intriguing patterns and nascent insights.

We find that international patent inflows and outflows both increase value-added trade on average, but that this effect is driven primarily by industries based in high-income countries. Indeed, these international patent flows have the opposite effect in middle-income countries where they lead to greater production fragmentation and declining value-added trade as share of exports, which can also be consistent with productivity enhancing integration into GVCs. Our results suggest that the relationship between patents and GVCs composition and structure is similarly distinct across high- and middle-income countries. While this analysis cannot pin down the mechanisms behind these heterogeneous results, candidate mechanisms include different compositions of patents, different patenting motives or strategies, and differential capacity to absorb new knowledge and technologies between high- and middle-income countries. Understanding how such differences systematically shape firm-level strategy and thereby alter the effect of patent flows on GVCs remains an important priority for future research. When we decompose estimated patent elasticities by sector and region, we see further dimensions of heterogeneity. Taken as a whole, the results suggest that both international and domestic patent flows can shape GVCs in ways that are statistically detectable and may therefore be relevant for the design, implementation and impact of innovation policy.

Several important limitations of this analysis merit some discussion and suggest potential next steps for future analysis along these lines. Because the opportunity to empirical test the relationship between patents and GVCs is new and as yet unexplored, we have opted for an essentially inductive approach in this chapter. As the evidence base deepens, it will be important to develop an analytical framework – perhaps formalized as a theoretical model – with which to generate testable hypotheses and through which to provide a richer interpretation of results. Such a framework would help to articulate the relationships and mechanisms that map patent flows into effects on GVCs. Since developing such a framework is beyond our scope here, we hope that our exploratory empirical work and the dominant country-industry patterns it detects prompts other work in this direction.

As is always the case in applied research, there is more we could do with more and better data. The source input-output data used to construct the GVC measures we use are complex and difficult to collect and construct. As these data become more widely available, empirical research into GVCs will continue to expand rapidly, which is likely to bring additional improvements in these data sources and modelling approaches. In our case, these input-output data are essentially non-existent for low-income countries, which is why we currently restrict our focus to high- and middle-income countries. During the years covered in this analysis, patent flows to, from and within low-income countries were very sparse, which would have limited the estimation of similar specifications for low-income countries even if their input-output data were available. Going forward, however, it will become increasingly important to understand the innovation and GVC dynamics in these low-income economies, many of which are changing rapidly. This is a critical research priority since the experience of middle-income countries over the past few decades may be a poor guide to the future prospects and possibilities faced by today's low-income countries.

In addition to improved input-output data, better measurement of cross-border trade in ideas (e.g., licensing and royalties) and more widely available firm-level data would help generate richer policy-relevant insights. Like our disaggregated analysis by income class, sector or region, which provides a clearer view of the heterogeneity hidden in average estimates, firm-level analysis would open the door to yet higher-level heterogeneity analyses to further unpack aggregate relationships and underlying mechanisms.

While better data – perhaps combined with case study-type analyses – might provide cleaner and more convincing estimates of the causal impact of patent flows on GVCs, it is important to note that there is an even more fundamental challenge to this and any other empirical exercise: Data analysis is always backward-looking. This limitation makes it difficult for this analysis to fit the "Digital Era" theme of this volume. The years covered in our analysis clearly pre-date the digital era as it is now understood and anticipated, which suggests that the patterns we detect may not be indicative of future relationships in which GVCs are more fully integrated into the digital economy. Given the candidate explanations we have in mind for the existence of (statistically-detectable) linkages between patents and GVCs, however, we believe the continued march into the digital era will only amplify the importance of this relationship.

Finally, for tractability, we have opted here for an essentially static, contemporaneous and uni-directional analysis. That is, we have sought to estimate the contemporaneous effect of patent flows on GVCs. Aside from the lags between patent applications and grants, which we leverage for predictive causality as described above, we do not introduce any dynamics between these moving and inter-dependent pieces. Consider, in conclusion, the opposite direction in this relationship – from changes in GVCs and value-added trade to patent-based (or more general) innovation. Given the intended effects of policy instruments aimed at upgrading a given country-industry's GVC position, understanding how enhanced GVCs shape subsequent innovation is potentially more interesting and more important. For example, how might greater production fragmentation impact domestic and international patenting? In a basic model of offshoring, increased production fragmentation allows the domestic firm to reallocate more workers towards higher-end production processes, which include R&D intensive industries. We would expect that countries that increase production fragmentation over time by becoming more integrated in GVCs to thereby benefit with higher levels of innovation. This would suggest that a declining *VAX* may lead to higher future levels of innovation and patent output. A richer understanding of these relationships, including through detailed case studies and firm-level microdata, is not only a laudable research pursuit, but one with clear and compelling policy implications. Results from such inquiries may ultimately help to guide innovation policies and strategies to stimulate investments in upgrading GVCs in ways that reflect important heterogeneity across countries, regions and sectors.

REFERENCES

Antras, Pol and Davin Chor. 2013. “Organizing the Global Value Chain.” Econometrica 81(6): 2127-2204.

Antras, Pol, Davin Chor, Thibault Fally and Russell Hillberry. “Measuring the *Upstreamness* of Production and Trade Flows.” American Economic Review Paper and Proceedings 102(3): 412-416.

Awokuse, T.O., and H. Yin. 2010. "Intellectual property rights protection and the surge in FDI in china." Journal of Comparative Economics 38(2):217-224.

Baldwin, Richard and Anthony Venables. (2010). “Relocating the Value Chain: Offshoring and Agglomeration in the Global Economy”. *NBER Working Paper 16611*.

Bosworth, Derek, “Foreign Patent Flows To and From the United Kingdom,” Research Policy, Vol. 13, No. 2, 1984.

Coe, David and Elhanan Helpman, “International R&D Spillovers,” European Economic Review, Vol. 35, No. 5, May 1995.

Costinot, Arnaud, Jonathan Vogel and Su Wang (2011). “An Elementary Theory of Global Supply Chains”. Review of Economic Studies 80: 109-144.

Eaton, Jonathan and Samuel Kortum, Josh Lerner, “International Patenting and the European Patent Office: A Quantitative Assessment,” Patents, Innovation and Economic Performance: OECD Conference Proceedings, 2004.

Fally, Thibault. "Production staging: measurement and facts." Boulder, Colorado, University of Colorado Boulder Mimeo. 2012.

Fromhold-Eisebith, M. 2007. "Bridging scales in innovation policies: How to link regional, national and international innovation systems." European Planning Studies 15(2):217-233.

Galindo-Rueda, F. and F. Verger (2016), “OECD Taxonomy of Economic Activities Based on R&D Intensity”, OECD Science, Technology and Industry Working Papers, 2016/04, OECD Publishing, Paris.

Harhoff, Dietmar and Karin Hoisl, Bettina Reichl, Bruno Van Pottelsberghe De La Potterie, “Patent Validation at the Country Level: The Role of Fees and Translation Costs,” Research Policy, Vol. 38, No. 9, 2009.

Harhoff, Dietmar, and Stefan Wagner. "The duration of patent examination at the European Patent Office." *Management Science* 55, no. 12 (2009): 1969-1984.

Ivus, O. 2010. "Do stronger patent rights raise high-tech exports to the developing world?" Journal of International Economics 81(1):38-47.

Johnson, Robert C. and Guillrmo Noguera (2012). “Accounting for Intermediates: Production Sharing and Trade in Value Added”. *Journal of International Economics*. 86(2)

Johnson, Robert C. and Guillermo Noguera. (2017). "Fragmentation and Trade in Value Added Over Four Decades". *The Review of Economics and Statistics,* 99(5).

Kim, Linsu 1997, "Imitation to Innovation - The Dynamics of Korea's Technological Learning", Harvard Business School Press.

Kim, Linsu, "Technology Transfer & Intellectual Property Rights – The Korean Experience", Intellectual Property Rights and Sustainable Development, June 2003, UNCTAD-ICTSD project on IPRs and Sustainable Development.

Kim, Kiheung, "Technology Transfer: The Case of the Korean Electronics Industry", The Hawaii Intenational Conference.

Lybbert, T.J. and Nikolas Zolas, 2014. Getting patents and economic data to speak to each other: An 'algorithmic links with probabilities' approach for joint analyses of patenting and economic activity. Research Policy, 43(3), pp.530-542.

Neubig, Thomas and Sacha Wunsch-Vincent, 2018 "A Missing Link in the Analysis of Global Value Chains: Cross-Broder Flows of Intangible Assets, Taxation and Related Measurement Implications", in *WTO Trade in Knowledge* (forthcoming). World Trade Organization.

Primo Braga, C., and C. Fink. 1999. "How stronger protection of intellectual property rights affects international trade flows." World Bank Policy Research Working Paper (2051).

Slama, Jiri, "Analysis by Means of a Gravitation Model of International Flows of Patent Applications in the Period 1967 – 1978," World patent Information, Vol. 3, No. 1, 1981.

Timmer, Marcel. (2012). "The World Input-Output Database (WIOD): Contents, Sources and Methods." *WIOD Working Paper Number 10*.

UNCTAD 2013, "Global Value Chains: Investment and Trade for Development" in *World Investment Report 2013,* Geneva.

Vichyanond, J. 2009. Intellectual property protection and patterns of trade: Center for Economic Policy Studies, Princeton University.

WIPO 2017a, "Patents" in *World Intellectual Property Indicators*, Geneva.

WIPO 2017b, *World Intellectual Property Report,* Geneva.

World Bank 2017, *Measuring and Analyzing the Impact of GVCs on Economic Development,* Washington, D.C. World Bank Group.

Yi, Kei-Mu (2003). "Can Vertical Specialization Explain the Growth of World Trade?" *Journal of Political Economy*, 111.

Yi, Kei-Mu (2010). "Can Multi-Stage Production Explain the Home Bias in Trade?" *American Economic Review*, 100(1).

Zolas, Nikolas (2014). “International Patenting with Heterogeneous Firms”, *CES Working Paper 14-28*.

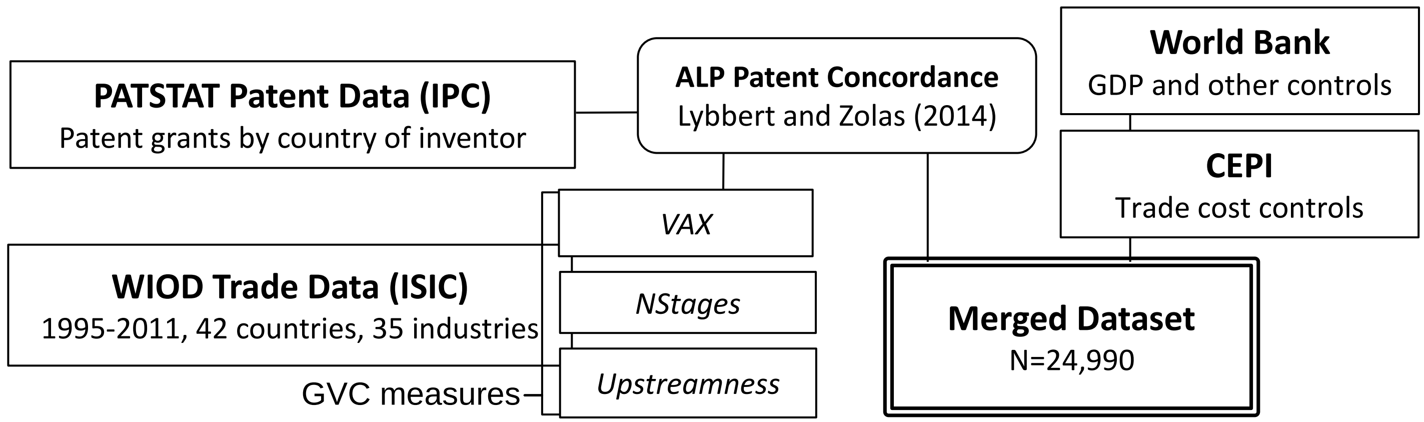

Figure 1: Construction of final merged dataset from PATSTAT and WIOD data

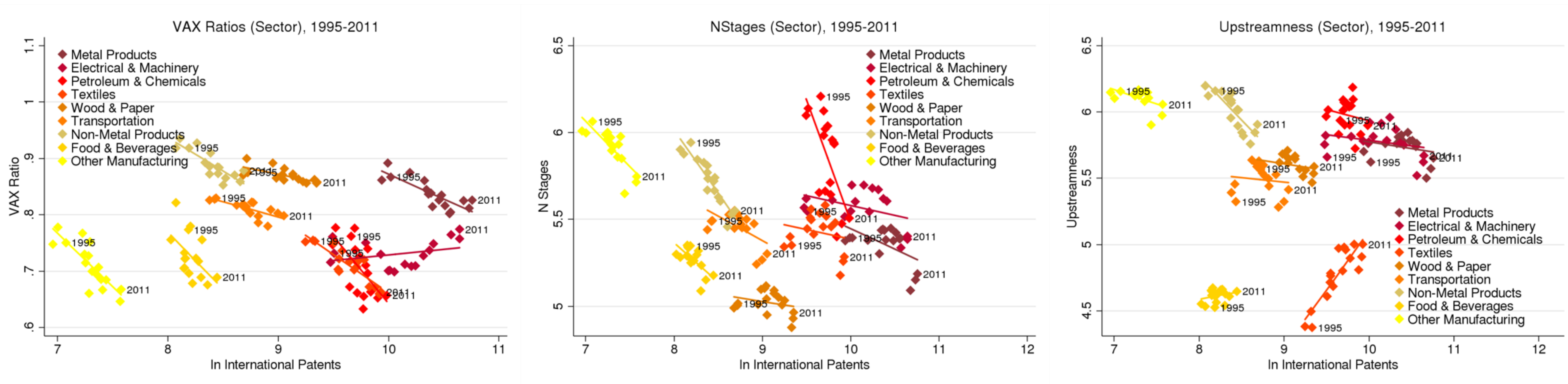

Figure 2: Yearly *VAX*, *NStages* and *Upstreamness* and International Patent Flows by Sector

Source: VAX Figures calculated using WIOD data (2013 Release) and the methodology described in Johnson & Noguera (2012). *NStages* figures calculated from same source data using methodology described in Fally (2012). *Upstreamness* figures calculated from same source data using methodology in Fally (2012) and Antras et al. (2013). The sectors are color coded and ordered according to their patent intensity: darker colors correspond to patent intensity.

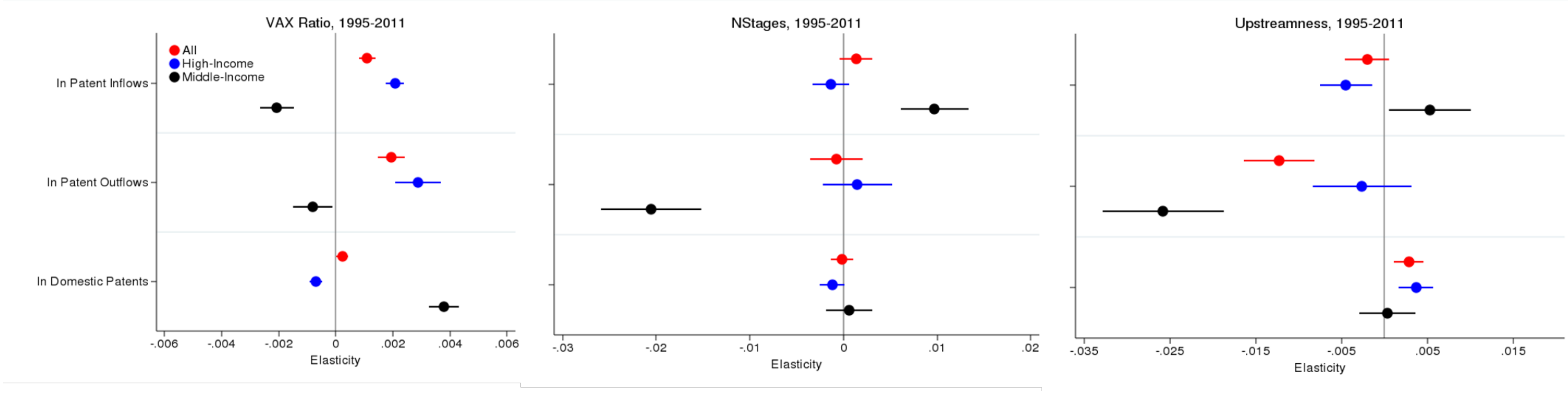

Figure 3: Estimated unilateral elasticities for *VAX*, *NStages* and *Upstreamness* with respect to patents with 95% confidence intervals based on robust standard errors

Notes: All regressions include country-industry fixed effects, year fixed effects and country-level control variables GDP, GDP per capita and WTO membership. Results reported in Tables A1 and A2 in appendix.

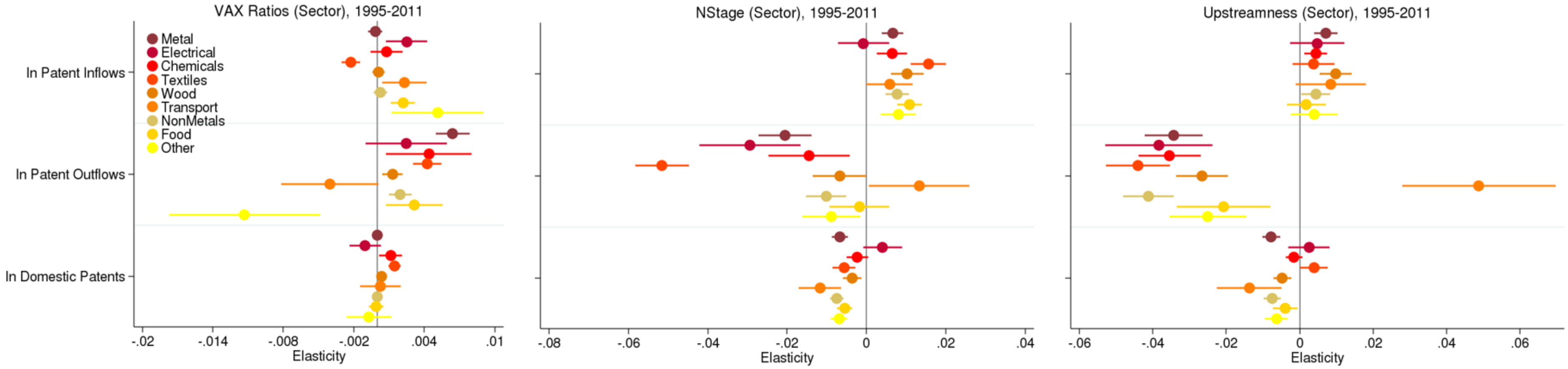

Figure 4: Regression Coefficients for *VAX*, *NStages* and *Upstreamness* based on Patent Flows by Sector

Notes: Confidence intervals based on robust standard errors clustered by industry in parentheses. All results based on within country-industry regressions and include country regressors of GDP, GDP per capita and WTO membership which are not reported here, along with country-industry fixed effects and yearly fixed effects. The sectors are color coded and ordered according to their patent intensity, with the darker color being the most patent intensive and the lighter color being the least.

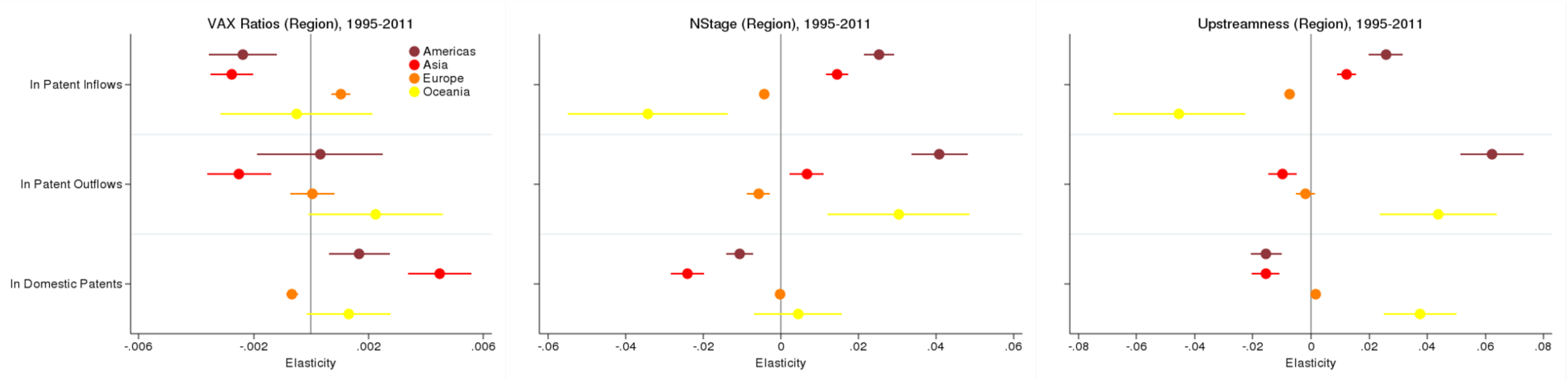

Figure 5: Unilateral Regression Coefficients for *VAX*, *NStages* and *Upstreamness* based on Patent Flows by Region

Notes: Confidence intervals based on robust standard errors clustered by industry in parentheses. All results based on within country-industry regressions and include country regressors of GDP, GDP per capita and WTO membership which are not reported here, along with country fixed effects, industry fixed effects and yearly fixed effects. Coloring indicates level of patent intensity with maroon being the most patent intensive (Americas) and yellow being the least patent intensive (Oceania).