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# Networks, Innovation and Productivity: A Conference Recap

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How do employment targets affect firm dynamics? What is the relationship between inventor migration, and local productivity and knowledge spillovers? How are surplus gains from inventions distributed? These were among the questions addressed by economists during a recent Richmond Fed research conference.

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Economists from the Richmond Fed, research universities and other institutions met in Richmond for a conference in May. Researchers presented papers on a variety of topics, including digital advertising, R&D allocation, production networks, and knowledge creation and diffusion.

## **The Expansion of Product Varieties in a New Age of Advertising**

Advertising is a crucial component of firm behavior. Recent improvements in advertising technology have allowed firms to better tailor advertisements to individual consumers' tastes, which has led to a significant reallocation of spending from traditional advertising to digital advertising. At the same time, the number of product varieties has increased as well.

Salome Baslandze of the Atlanta Fed presented the paper "[The Expansion of Product Varieties in a New Age of Advertising](#)," which aims to shed light on the relationship between technological progress in digital advertising, product varieties and consumer welfare. The paper was co-authored with Jeremy Greenwood and Ricardo Marto of the University of Pennsylvania, and Sara Moreira of Northwestern University.

The authors hypothesize that improvements in the efficiency of digital ads have led to an increase in spending on digital ads and in the number of product varieties. More specifically, as targeting becomes more refined, firms are incentivized to produce varieties of a product that can be sold at higher prices relative to more generic versions.

Using data on advertising spending (with digital and traditional separated) and the number of product varieties for the period 1995-2019, the authors find a positive correlation between the number of product varieties and digital ads. They also use data on local-level internet availability (which is a proxy for the intensity of digital advertising) to show that greater internet access is associated with a greater availability of product varieties.

The authors support this finding with a theoretical model that assumes firms are better able to target their advertising more precisely over time. As a result, demands by customers for specialized varieties increase, which motivates firms to expand product variety.

They calibrate the model to data from 1995 and from 2015 to match several facts regarding the new era of digital advertising, including:

- The ratio of total advertising spending to GDP
- The ratio of digital to traditional advertising
- The increase in product lines and their associated varieties over the years

During this period, they find that directed digital advertising increases the number of product lines and varieties contained within those lines. At the same time, economic welfare increases.

### **Committing to Grow: Employment Targets and Firm Dynamics in East Germany**

During German Reunification in the 1990s, over 12,000 East German firms once owned by the state were sold to private buyers. As a part of that transition, the government asked those buyers to commit to firm-specific employment targets that were enforced through audits and penalties. Ultimately, these labor target commitments were included in 18,000 contracts and covered more than 900,000 East German workers.

Ufuk Akcigit of the University of Chicago presented research examining the implications of these employment targets on firm dynamics during this period. His paper, "[Committing to Grow: Employment Targets and Firm Dynamics in East Germany](#)," was co-authored with Harun Alp of the Federal Reserve Board, Andre Diegmann of the Halle Institute for Economic Research and Nicolas Serrano-Velarde of Bocconi University.

The authors quantify the welfare implications of the employment target policy by considering how it constrained firm optimization and how it incentivized productivity growth. To do so, they use contract-level information regarding terms of the employment commitments (including agreed-upon dates and deadlines) as well as the dates and results of each on-site audit. Their quantitative analysis yields three main findings:

- The policy distorted firm-size choices, as firms bunched around their employment targets.
- Firms under tight contracts — where initial employment levels were below target — experienced 67 percent employment growth and had productivity growth 8 percent to 14 percent higher than that of firms with non-tight contracts.
- Those tight commitments, however, led to increased costs, which lowered profits and made those firms more likely to exit.

The authors develop a dynamic model of firms to interpret these findings. First, the model shows that the combination of upward-distorted labor choices (that is, having more employees than necessary) and penalties lowers firm profits and generated higher exit rates. Second, the model demonstrates that these same firms experienced higher *marginal* profits because their increased productivity not only increased profits but also reduced distortion and penalties. This suggests that over time, distorted firms were more

willing to improve their productivity over time. The authors refer to this as the "catch-up" effect of tight contracts.

The authors then calibrate the model to the data, which shows that 12 percent of the employment growth these firms experienced was due to the higher productivity growth that results from tight contracts. Further, across three years of labor commitment policy, the German economy experienced an increase of 3 percentage points in aggregate total factor productivity growth due to the increased production of firms with tight contracts.

### **Supplier Churn and Growth: A Micro-to-Macro Analysis**

What is the role of supplier entry and exit in driving growth? Existing models suggest that new suppliers create value for their customers by expanding either the variety or quality of goods they sell, which generates trade and growth. To build on this understanding, David Baqaee of UCLA presented the paper "[Supplier Churn and Growth: A Micro-to-Macro Analysis](#)." The paper was co-authored with Ariel Burstein of UCLA, Cédric Duprez of the National Bank of Belgium and the late Emmanuel Farhi of Harvard University.

The authors introduce the "inframarginal surplus" ratio, which quantifies how much surplus accrues to consumers from additional suppliers per unit of expenditure. To estimate this statistic, they employ data from Prodcom, a detailed survey of Belgian manufacturing firms' sales and quantity data. Linking this data with VAT returns — which contain firm-to-firm input-output linkage information — they first focus on the microeconomic level, demonstrating the value of suppliers to firms. To do so, they calculate the effect of firms' supplier separations (or contract terminations) on their marginal costs. Their analysis reveals that the value of suppliers to a firm is significant, as a firm's marginal costs increase by about 0.6 percentage points for every 1 percent of suppliers lost.

Turning to the macroeconomic effects of what they call "supplier churn" on aggregate growth, the authors develop a framework that accounts for how the creation and termination of supplier links affects the prices of downstream firms and how these price changes move along supply chains all the way from suppliers to final consumers. When applied to the data from the Belgian economy, they find that almost all aggregate productivity growth can reasonably be attributed to supply chain churn.

### **Innovation Networks and R&D Allocation**

When thinking about how to best foster innovation, economists and policymakers have focused extensively on the efficient allocation of resources towards research and development (R&D). An understudied dimension of this question involves determining the optimal distribution of R&D resources across economic sectors and technological fields in a way that allows for cross-sector knowledge spillovers and furthers long-term economic growth. To further explore these issues, Ernest Liu of Princeton University presented the paper, "[Innovation Networks and R&D Allocation](#)." The paper was co-authored with Song Ma of Yale University.

To determine the optimal allocation of R&D resources in an economy, the authors introduce a multisector growth model with an innovation network, which captures the idea that one sector's innovation efforts demand that its researchers and scientists build on knowledge and findings from other fields.

The model yields two key insights. First, planners and policymakers generally should direct more resources to sectors central to the innovation network, such as semiconductors. Here, these technologies can generate persistent knowledge spillovers both directly and indirectly, which will foster growth in both the present and the future. Second, the extent to which planners should invest in those central sectors is determined by how much the economy can capture knowledge spillovers from abroad. To maximize domestic welfare in countries that rely on knowledge spillovers, those planners should allocate fewer R&D resources into their network-central sectors.

The authors construct a global innovation network containing over 36 million patents and their citations from 40 major global patent authorities to test these implications. They find significant variation in the extent to which countries rely on foreign spillovers: 70 percent of U.S. patent citations are toward other U.S. patents, but most other economies — including China, South Korea and Germany — rely on foreign patents.

For the U.S., the analysis suggests that its central sectors — medical science, semiconductors and computers — rank highly in optimal allocation of resources. Regarding other countries, the analysis suggests that Germany and Japan should focus their resources on vehicle innovations and China and South Korea should invest in electric communication technology. Finally, the authors find that Japan has the most efficient R&D resource allocation.

Also, for the period 2010-2014, moving to Japan's level of allocation efficiency improves consumption-equivalent welfare by 19.6 percent in the U.S., 15.6 percent in China, 12.5 percent in South Korea and 10.3 percent in Germany.

### **The Global Race for Talent: Brain Drain, Knowledge Transfer and Growth**

The migration of high-skilled knowledge workers is a contentious topic in academic and policy debates. For origin countries, fear of a "brain drain" is countered by the benefits that come with knowledge transfers back to those countries by emigrants. Conversely, host countries reap the benefits of valuable talent coming to their shores, but that talent can displace native workers.

Marta Prato of Yale University presented the paper "[The Global Race for Talent: Brain Drain, Knowledge Transfer, and Growth](#)," which addresses how inventors' migration decisions affect international talent allocation, knowledge diffusion and productivity growth.

Prato first presents a two-country innovation-based growth model where inventors innovate, learn from others and make dynamic migration and return decisions. These migrant inventors interact with other inventors at origin and at their destination, creating a knowledge network that diffuses within and across countries.

Prato models data on patents from migrant inventors on the U.S.-EU corridor and shows that:

- Overall migration is asymmetric, with net emigration from the EU to the U.S.
- Migrants increase their patenting by 42 percent per year after migrating.
- Migrants continue to work with other inventors at their origin even after moving, although they are more likely to collaborate with others in the same location or from the same origin.
- Local inventors at origin increase patenting by 15 percent per year after a collaborator emigrates.

To examine the effects of real-world policy interventions, Prato then conducts a counterfactual exercise with the data that simulates a European Union tax cut for foreigners and return migrants, as well as a change in U.S. visa caps.

With respect to the EU tax cut — which has the purpose of eliminating brain drain — the simulation reveals that innovation in the EU increases in the short run and declines in the U.S. in the long run, lowering technology diffusion from the U.S. to the EU. As a result, productivity growth increases in the EU by 5 percent in the first 25 years but declines by 6 percent in the long run. Turning to U.S. policy, doubling the H-1B visa cap increases brain drain from the EU to the U.S. Also, productivity growth in the EU declines by 4 percent in the short run but increases by 9 percent for both the U.S. and EU in the long run.

### **Knowledge Creation and Diffusion With Limited Appropriation**

Both the creation and the diffusion of knowledge are key to economic growth. But the two are sometimes in conflict. For instance, restrictive patents can encourage innovation by increasing the benefits inventors receive for their new ideas and techniques. However, such patents also tend to inhibit the diffusion of new techniques across an economy.

There is a long literature that debates the pros and cons of strong patent rights. A recent branch of that literature began with the 2009 paper "[Ideas and Growth](#)." His approach was to model diffusion as a contagion process where lagging firms gain knowledge from more advanced firms through random matching. In the ensuing literature, models of this type have tended to operate under the assumption that the economic surplus generated by an invention is fully appropriated by the receiving firm.

Hugo Hopenhayn of UCLA presented research that explores a wider range of assumptions about how the surplus gains from inventions are distributed. His paper, "[Knowledge Creation and Diffusion with Limited Appropriation \(PDF\)](#)," was co-authored with Liyan Shi of the Einaudi Institute for Economics and Finance.

There are many cases, the paper observes, where substantial parts of the surplus from an invention are retained by the transferring firm (the initial owner of the invention). Such is the case with technology transfer licenses. The paper captures this possibility by modelling knowledge transfer as a bargaining problem between the transferring and acquiring parties. The authors explore the implication of shifts in relative bargaining power and their implications for knowledge creation and transmission.

Exploring a simple, one-period model in which all firms are initially identical, the authors demonstrate that economic growth is maximized when relative bargain power is at an intermediate point (and not favoring either side to an extreme). Relaxing these assumptions, they explore the role of heterogeneity. They find that, when firms differ in their initial levels of productivity, those above a certain threshold choose to innovate while those below choose to learn from the innovators. Moreover, the authors find that, as ex-ante heterogeneity increases, the optimal bargaining weight for innovators decreases, and it becomes zero when heterogeneity is sufficiently high.

However, they find that the optimal bargaining weight for innovators increases when the notion of creative destruction is added to the model through a mechanism by which the innovator's competitive position is harmed by subsequent adopters.

## **Spatial Production Networks**

A key feature of the global economy is the geographic complexity of its production networks. Making products like automobiles or smartphones requires numerous steps fragmented across countries and regions. Research has confirmed that this geographical complexity has deepened over the past decade. A burgeoning academic literature has enhanced understanding of production networks from both microeconomic and macroeconomic perspectives. The microeconomic approach focuses on how firms endogenously form production networks, while the macroeconomic approach focuses on how macroeconomic conditions in a country or region are influenced by the topography of production networks.

Costas Arkolakis of Yale presented research that uses new theory and data to study how firms endogenously form production networks and how these networks shape the spatial distribution of aggregate economic activity. His paper, "[Spatial Production Networks \(PDF\)](#)," was co-authored by Federico Huneeus of the Central Bank of Chile's research department and Yuhei Miyauchi of Boston University.

The authors begin by discussing a set of motivating facts that show how firms' network decisions are influenced by their fundamental characteristics and geographical location. They point out that firms with greater revenues tend to have more suppliers and buyers, as do firms based in more densely populated areas. In addition, they point out that both the number of supplier-to-buyer relationships and the transaction volume per relationship tend to decrease with increasing geographic distance. In other words, firms tend to trade less often with more distant trading partners.

The authors then present a model of spatial production networks built upon microeconomic foundations. In the model, network structures arise endogenously from the decisions that firms make based on their productivity and location. Firms search for suppliers and buyers across locations to maximize their anticipated profit, subject to search costs specific to each potential buyer-seller relationship. Their model predicts that the most highly productive firms will tend to form the greatest number of supplier and buyer relationships and make higher revenues, a result that is consistent with the empirical evidence.

The authors aggregate across firms to examine how trade flows are affected by changes in both the number of supplier-to-buyer relationships and the transaction volume per relationship. In addition to search costs, they account for so-called "iceberg" transaction costs — that is, costs that depend on the distance between trading parties. To evaluate the quantitative implications of endogenous production network formation, the authors calibrate their model to the observed domestic and international trade flows across municipalities and sectors within Chile and its cross-border trading partners.

They find that both iceberg and search frictions have important effects on trade patterns. The researchers argue that focusing solely on iceberg trade costs (as many studies have done) may yield a biased picture of a regions' spatial linkages and economic activity.

## **Firm-to-Firm Trade: Imports, Exports and the Labor Market**

International economists have started examining customs records data, which describe the most granular units of cross-border trade. These records reveal the activities of individual buyers and sellers that underlie aggregate trade flows, which have been the object of many earlier studies.

Some striking regularities emerge, such as the positive correlation between an export market's size and the number of individual firms exporting to the market. For example, a greater number of French firms export to Germany than Belgium.

The customs data also reveal patterns among importers. One of these is the positive relationship between the number of customers a typical exporter has in a foreign market and the overall size of the foreign market. For example, the average French exporter has more customers in Germany than in the considerably smaller economy of Denmark.

Samuel Kortum of Yale presented research that seeks to capture both the heterogeneity and the granularity of individual buyer-seller relationships in a general equilibrium model. His paper, "[Firm-to-Firm Trade: Imports, Exports, and the Labor Market](#)," was co-authored by Jonathan Eaton of Brown University and Francis Kramarz of the Center for Research in Economic Statistics at the Institut Polytechnique De Paris.

Their model describes a world in which trade is conducted through random meetings. Buyers — both households looking for final products and firms looking for inputs — connect with sellers randomly. In contrast to standard production theory, the model treats firms' production technology as a combination of tasks. Each task can be performed by labor of different types, but firms can also use intermediate goods to substitute for labor. In the model, a firm's cost in a market depends not only on its underlying efficiency, but also on the costs of its suppliers.

At the firm level, the model generates predictions for imports, exports and the share of labor in production broadly consistent with observations on French manufacturers. At the aggregate level, firm-to-firm trade determines bilateral trade shares as well as labor's share of output in each country. One of the model's implications is that a reduction in trade barriers can reduce the share of labor in production by giving producers access to additional and cheaper sources of supply.

### **Two-Sided Market Power in Firm-to-Firm Trade**

The 2018 U.S.-China trade war spurred new interest in tariff pass-through literature. The conventional wisdom at the time (based on traditional trade theory) suggested that tariffs imposed by a country as large as the U.S. would be mostly absorbed by foreign firms, leaving domestic prices mostly unchanged.

It turns out, however, that this was generally not the case. Most U.S. industrial sectors saw a near-complete tariff pass-through into the domestic prices of imported goods. The steel industry was one of the few exceptions.

Monica Morlacco of the University of Southern California presented a novel theory of international pricing that attempts to account for this seeming discord between prevailing theory and empirical evidence. Her paper, "[Two-Sided Market Power in Firm-to-Firm Trade](#)" was co-authored with Vanessa Alvarez of the Inter-American Development Bank, Michele Fioretti of Sciences Po, and Ayuma Ken Kikkawa of UBC Sauder.

Noting that about 80 percent of international trade involves global value chains (GVCs), the authors argue that the prevalence of these global production networks suggests that theories of international prices need to be built around key GVC characteristics. Prominent among those is that the networks are

dominated by large firms that enjoy bargaining power in the markets in which they buy and sell. Moreover, intermediate input purchases within GVCs can involve significant "lock-in" effects, resulting in transaction prices between buyers and suppliers being bilaterally negotiated.

The authors' model sets out a theory of prices in firm-to-firm trade with two-sided concentration and market power. In the model, the scope for concentration and market power depends on two unobserved sets of parameters:

- The supply elasticity of exchanged goods
- The bilateral bargaining weights of importers and exporters

Estimating the model, the researchers use a novel identification strategy to measure the micro-level and macro-level implications of two-sided market power for U.S. import prices.

The researchers emphasize three results:

- Their estimates of bilateral bargaining weights and input supply elasticities are consistently in the range where "two-sided concentration" and bargaining power matter for international prices.
- The model generates more accurate predictions of pair-level price changes following a tariff shock than standard pricing models in the literature.
- Their model provides a more accurate estimate than standard trade models of the 2018 trade war's effect on aggregate U.S. import prices.

### **Cascades and Fluctuations in an Economy With an Endogenous Production Network**

Production in modern economies involves complex networks of specialized firms, each buying inputs from suppliers and selling their own outputs to downstream producers. Recent research has shown that the structure of such networks has important implications for economic outcomes. At the micro level, network structure influences the size of firms and how they withstand shocks. At the macro level, it affects how idiosyncratic shocks contribute to aggregate fluctuations. Despite their importance, however, relatively little is known about how network structures are shaped by economic forces.

Mathieu Tashereau-Dumouchel of Cornell University presented his paper "[Cascades and Fluctuations in an Economy with an Endogenous Production Network](#)," which proposes a new theory to address how production networks are formed, how they respond to shocks and how they influence the propagation of such shocks throughout an economy.

A distinguishing feature of the theory is that it focuses on firms' "extensive margin" of production. A firm's extensive margin relates to its acquisition of new customers (and the loss of existing customers). This is in contrast to a firm's "intensive margin," which relates to fluctuations in its sales to pre-existing clients.

The focus on the extensive margin makes the model particularly well suited for analyzing economic shocks that cause firms to go out of business. To restart operations, such firms must work on their extensive margins by rebuilding severed customer connections and finding new customers.

In the model, firms combine intermediate inputs from their suppliers using production technology with a constant elasticity of substitution (CES). With CES production functions, a firm can lower its marginal cost



of production by gaining access to additional sources of inputs. These gains from input variety make firms with multiple suppliers more likely to withstand shocks and continue to operate. Similarly, firms with multiple customers are also more likely to withstand shocks.

In this way, the model's assumption of CES production technology creates complementarities between the operating decisions of nearby firms. The complementarities lead to the creation of clusters of firms that are tightly connected with one another. But the complementarities also create the possibility of cascades of firm failures following highly adverse economic shocks.

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