

# Editor's Overview

This 39th issue of the *International Productivity Monitor* contains six articles. Topics covered are The Productivity Institute recently established in the UK, the short-term productivity effects of the pandemic in Canada, productivity performance in G7 countries since the financial crisis, manufacturing productivity in the Nordic countries, and review articles on volumes on economic and productivity growth and the economics of artificial intelligence.

Advanced economies have experienced slower productivity growth in recent years, with negative implications for growth in living standards. Consequently, governments are searching for measures to foster productivity growth. This means it is particularly important for governments to understand the causes and nature of the productivity slowdown and the effectiveness of specific policies to enhance productivity. Recognizing the key role for research in this process, the United Kingdom has recently established The Productivity Institute to advance understanding on the productivity issue.

In the lead article in this issue, **Bart van Ark**, Managing Director at The Productivity Institute and Professor at the University of Manchester and **Tony Venables**, Research Director at The Productivity Institute and Professor at the University of Oxford, provide an overview of the mandate of the new organization, outline the eight themes of its research agenda, and discuss the contours of its engagement with the academic, business, and policy communities. A unique feature of the Institute is that its governance structures ensure that its comprehensive and high-quality research will be a key input into government policies to improve productivity.

In 2020, the world economy has been

badly shaken by the COVID-19 pandemic, with important effects for both short-term and long-term productivity developments. In the second article in the issue, **Joel Blit** and **Mikal Skuterud**, both from the University of Waterloo, and **Michael R. Veall** from McMaster University examine short-run changes in output, hours worked, and output per hour in 87 Canadian industries. The authors examine the role of three industry characteristics (proportion of employed who work from home, the health risk, and proportion of workers facing customers) in explaining industry productivity developments. Perhaps surprisingly, they find no evidence of association between these characteristics and productivity changes.

Any understanding of aggregate productivity growth requires knowledge of the industry sources of this growth. In the third article, **Jianmin Tang** from Innovation, Science and Economic Development Canada and **Weimin Wang** from Statistics Canada present estimates of industry contributions to aggregate productivity growth for the G7 countries for the 2000-2010 and 2011-2015 periods using KLEMS datasets. The authors find that in 2011-2015, Canada enjoyed the fastest business sector labour productivity growth among G7 countries and experienced the largest acceleration

in productivity growth compared to 2000-2010. Manufacturing had made a very large negative contribution to aggregate productivity growth in Canada in 2000-2010, due to the declining relative prices of manufactured goods and the fall in the size of the sector. These negative contributions were much less or reversed in 2011-2015, making manufacturing the driving force for the improvement in Canada's productivity performance after the financial crisis.

The measurement of labour productivity at the industry level can be approached from two perspectives. The first is where the direct labour in an industry is related to the real value added produced by that industry. The second is a vertically integrated perspective where all domestic labour embodied in a product, including that in the intermediate inputs, is related to the gross output of an industry. In the fourth article, **Daniel Lind**, Chief Economist at the Swedish trade union Akavia, develops the vertically integrated perspective to productivity for manufacturing industries in four Nordic countries labour. He makes the case that this perspective is becoming more important since knowledge capital is increasingly embodied in intermediate goods. Lind finds that Norway has greatly improved its manufacturing productivity performance since 2001 and is now the Nordic leader in this area.

Dale W. Jorgenson, the Samuel W. Morris University Professor at Harvard University, has long been a leader in the productivity field. In recognition of his many seminal contributions over six decades, his long-time collaborator Bar-

bara Fraumeni has edited a festschrift entitled *Measuring Economic Growth and Productivity: Foundations, KLEMS Production Models and Extensions*. The volume includes 22 articles by 58 authors. In the fifth article, **Gilbert Cette** from the Banque de France and Université d'Aix-Marseille reviews the articles in the volume and provides his perspective on both the productivity paradox and the meaning of total factor productivity. He concludes that the volume is a valuable compilation of research on productivity topics and represents a honourable tribute to Dale W. Jorgenson.

In discussions on the prospects for future productivity advance, the development of artificial intelligence (AI) is often pointed to as a factor that may considerably boost trend productivity growth. In the sixth and final contribution to the issue, **Eric Santor** from the Bank of Canada provides a review article on the NBER volume *The Economics of Artificial Intelligence: An Agenda* edited by Ajay Agrawal, Joshua Gans, and Avi Goldfarb, all from the University of Toronto. Santor highlights the key contributions of the chapters and adds his perspective. He notes that grand debate is on how large the net benefits of AI will be for the economy and society. The contributors generally take a positive view of the impact of digitalization although the distribution implication of AI are well recognized. Santor concludes that the volume represents a comprehensive and for the most part accessible contribution to our knowledge of the economics of AI and will serve as a useful primer on the subject.

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# A Concerted Effort to Tackle the UK Productivity Puzzle

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## ABSTRACT

The United Kingdom has suffered an extreme version of the “productivity puzzle” – the strong and largely unexplained slowdown in productivity growth among OECD economies since the mid-2000s. In recognition of the challenges that weak productivity growth and low levels of productivity create for economic performance, living standards, and distribution of income across regions, a new research institute has been set up to advance the understanding of the problem. The Productivity Institute will create a comprehensive and interdisciplinary research agenda and contribute to the frontier of knowledge creation in productivity research in the UK and around the world. The Institute will focus on innovative ways to improve productivity performance, providing new insights to help policy and business leaders understand better how to raise productivity and thereby raise living standards in a sustainable manner. This article outlines the overall approach to research, engagement and capacity building by the Institute.

In recent decades productivity has become a major drag on the British economy. The long-term underperformance of productivity threatens economic growth and shared prosperity across the nation. The UK’s productivity puzzle has many dimensions, manifesting themselves differently across regions and sectors. This includes low productivity growth by international standards since the mid-2000s, a large number of low productivity firms, and large variations in performance across and within regions. Yet, at the same time, there are examples of innovation flourishing (even in some of the worst performing regions) where sectors, firms and local business initiatives are generating new products, services and ways of working.

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Several short- to medium-term developments present fresh challenges to the UK's productivity performance. In the short-term, the COVID-19 crisis and the associated recession have created an unprecedented fall in output and productivity. As the economy recovers the opportunities to raise productivity provided by new technology and innovation may be offset by damage to and scarring of underlying sources of productivity growth, in particular labour. Business dynamics will shape the extent to which ailing firms are replaced by firms that are more productive. The implementation of Brexit will provide challenges to productivity in the tradeable sector of the UK economy through impacts on supply chains, market access, and firms' locational choices. Non-tradable sectors will be impacted through new immigration rules.

In the medium- to long-term important societal transitions will provide opportunities for productivity growth but can also exacerbate the problem and worsen the trend if not addressed in a systematic and coordinated way. While new technologies offer great potential for faster productivity growth, their slow and uneven adoption, as well as specific challenges such as cyber and data security, pose further productivity risks. Similarly, without appropriate coordination of activities the drive towards net-zero carbon emissions could be detrimental to productivity.

The Productivity Institute, made possible by an initial five-year investment of £26

million by the UK Economic and Social Research Council (ESRC) complemented by a £6 million contribution from its nine participating academic and research institutions, is a response to these challenges. It will pinpoint the causes of the stagnation in UK productivity and identify new and innovative solutions, laying the foundations for a new era of sustained and inclusive productivity growth.<sup>2</sup> More specifically, its objectives are to:

- Advance the understanding of UK productivity performance with an agenda that identifies gaps, supports frontier research, and facilitates interdisciplinary work.
- Act as a transformational national hub, with extensive regional reach, bringing together academics and stakeholders from private, public and third sectors to develop innovative research, policy ideas, and business practices.
- Build capacity across universities, businesses, policy bodies and public and third sector organizations through engagement, fellowships and funding.

The first section of the article summarizes our current understanding of the productivity puzzle in the UK in an international and regional context. The second section discusses the contours of a research agenda around eight initial research themes, including human, knowl-

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<sup>2</sup> The nine institutions are the University of Manchester, where the Institute is headquartered, the University of Cambridge, Cardiff University, the University of Glasgow, King's College London, the National Institute of Economic and Social Research, Queen's University Belfast, the University of Warwick, and the Economic Statistics Centre of Excellence (ESCoE).

edge and organizational capital; geography and place; macroeconomic trends and policy; institutions and governance; social, environmental and technological transitions; and measurements and methods. The last section addresses how the Institute will implement its research agenda by directly linking it to the business and policy needs at national and regional level in the UK.

This article outlines the overall approach to the research, engagement and capacity building programmes by the institute. A comprehensive research agenda and implementation plan will be available in the spring of 2021, based on a series of workshops and the production of scoping papers. These papers will take stock of research knowledge and also assess the challenges across five regions in England as well the three devolved nations, Northern Ireland, Scotland and Wales. The research program will contribute to the advancement of knowledge creation on productivity issues around the world, and connect with research institutions and policy organizations internationally.

## **Why Does UK Productivity Lag and How to Close the Gap?**

It should be noted upfront that the slowdown in productivity growth over the past two decades is not a unique UK problem, and the phenomenon has been widely documented across advanced economies (OECD, 2019; Bauer *et al.*, 2020) and for the global economy (Dieppe, 2020; The Conference Board, 2020). There are multiple causes for the productivity slowdown. One global effect stems from an exhaustion of catch-up potential in emerging markets, which has also impacted other coun-

tries with which they trade. The drag from the global financial crisis is manifest through low demand, weak investment, inappropriate fiscal policies, and too low interest rates causing misallocations (Cette *et al.*, 2016; Syverson, 2016; Fernald *et al.*, 2017). There is evidence that the low hanging fruit from innovations has begun to dry up, and that there exists a significant time lag between invention and adoption of new (mainly digital) technologies (van Ark, 2016; Crafts, 2018; van Ark *et al.*, 2020).

Nevertheless, the productivity performance of the United Kingdom lags other advanced economies in at least three ways. First, since the 1960s there has been a persistent gap in levels of productivity compared to other countries at similar levels of development. Whereas UK output per hour was at about the same level as that of the EU-15 (that is excluding the new member states from Central and Eastern Europe) in the early 1960s it had dropped to more than 15 percent below the EU-15 level by the late 1970s, although it gained some ground during the 1990s and early 2000s (The Conference Board, 2020).

Second, since the mid-2000s UK productivity growth has weakened more than in other countries: between 2004 and 2019, EU-15 labour productivity increased at 0.6 per cent compared to a UK rate of 0.4 per cent. Hence, the relative gap has widened.

Third, the gap in productivity across regions in the UK is much wider than among regions in other OECD countries; in the UK the disparity between the most productive region (Inner London West) and the least (Cornwall) was more than 2:1 in 2017, whereas such differences are much smaller in other European countries where they are

typically between 1.3 and 1.8, with the exception of Poland and Romania (Zymek and Jones, 2020). More detailed analysis shows that this is not just a reflection of London being a high productivity outlier. There are large productivity differences between regions, and many large UK cities do not have the high productivity that is associated with city size in many other countries (McCann and Vorley, 2020).

The proximate reason for the UK's poor productivity record is a chronic underinvestment in its key growth drivers. Productivity is driven by technological change and innovation which, in turn, depend on investment in human and physical capital, as well as in other "missing capitals" such as intangible assets. The UK is in the bottom third of OECD countries for the share of output going to fixed capital formation, R&D spending, and hard and soft infrastructure investment (Mason et al., 2018). There are likely gaps in human capital, physical capital, and intangible assets, although those are poorly measured.

The deeper question is, why is the UK lacking – or misallocating – these complementary investments? In order to understand these issues research is required into the obstacles faced by people, firms, and places in attaining the capabilities required to invest and to achieve higher levels of productivity. One factor relates to the incentives created through public and private financing of productivity supporting investments. Another factor relates to the coordination of productivity-enhancing policies, including industrial policy, labour market policy, competition policy, science, innovation and education policies. Important culprits may be fragmented decision

making and the absence of well-functioning ecosystems involving business, government and research institutions at local, regional and national level, which operate in a coherent, coordinated and long-term manner. Many policy initiatives suffer from over-centralization, a top-down approach, short-termism linked to the electoral cycle, silos and the absence of effective joined up government, as well as lack of meaningful engagement with stakeholders (both governmental and non-governmental) beyond Westminster and Whitehall, and a disjointed, constantly changing approach to both policy-making and policy-delivery (Jones, 2016).

Widening the lens beyond the specific UK issues, while productivity is generally understood to be the only source of sustained economic growth, there is much less clarity about how it contributes to broader performance measures, such as living standards, well-being, a fair distribution of incomes and opportunities, and the creation of a net-zero carbon economy. The distribution of the gains from productivity growth depend on the sectors, places, and workers that experience productivity increases, and there are particular concerns about the effect of labour saving technological progress on the distribution of income. Understanding the distributional effects that follow from these drivers of productivity growth is as important as understanding their aggregate impacts.

## **Contours of a Research Agenda**

To substantiate the diagnosis of the productivity puzzle outlined above, The Productivity Institute will initially organize its research around eight themes, and our mo-

tivation for picking these themes is outlined below. Over the next few months the Institute's research team will develop the key research questions and approaches. The themes will expand and evolve over time, as researchers work across disciplines including economics, management and innovation sciences, political science, sociology, psychology, engineering and data science, to look systematically for innovative approaches and methods. It is likely that some of the solutions to tackle the productivity puzzle will be found at the nexus points where research questions touch on multiple themes.

Three of the eight themes are organized around the core areas of complementary investments: human capital, knowledge capital and organizational capital.

### **Human Capital**

The UK labour market is characterized by strength in high-end skills, but is weak on vocational skills and has a relatively low level of basic skills such as numeracy and literacy (Rincón-Aznar *et al.*, 2015). The supply of skills through the school and higher education system is thought to be problematic, as the UK educational system has traditionally placed greater value on academic attainment and lower value on vocational skills compared to comparator nations such as Germany and France.

There has been a highly elastic supply of labour from EU countries, many coming from places with significantly lower wages than the UK. And there is a high degree of labour market flexibility, particularly relatively low firing and hiring costs compared to many EU countries. A widely held view is that these features provide

little incentive for firms to train workers or participate in apprenticeship schemes, and are not conducive to capital-deepening investments. There is controversy as to whether or not the use of migrant labour in a relatively deregulated labour market has contributed to productivity (Portes, 2018; Oulton 2019).

Lacking from much of the policy debate is an understanding of how skills are moulded and deployed within the rapidly changing world of work, particularly as businesses respond to new technologies and competitive pressures to innovate in their products and processes. Workforce skills constitute a fundamental productive asset for any organization and yet we know little about how skill use and skill strategy interact with technologies within the workplace to shape productivity, nor about which workers gain and lose in the process.

This suggests a research agenda looking at three key areas. First, the relationship between the UK's training system and required labour skills. Second, labour market policy and regulation, including worker rights, minimum wages, and international labour mobility. And third, the engagement of firms in developing on-the-job skills and new competencies for occupations at a task-based level. An important aspect of the firm-employee relationship is the relationship between productivity and well-being in the workplace (for example, through employee engagement). Well-being in the work place is an end in itself but can also be a means to higher productivity.

### **Knowledge Capital**

The UK is thought to be good at pure re-

search and invention, but poor at commercializing the knowledge generated. This is an old and perhaps outdated stereotype, but there have been business and policy concerns that too many British tech firms are sold overseas rather than continue to grow the enterprise in the UK. At the same time, both private and public spending on R&D are low (Forth and Jones, 2020). There is relatively slow diffusion of new technologies – such as digital – into small- and medium-sized businesses (SMEs) (Jones, 2014; Jibril *et al.*, 2020).

These concerns create research and policy challenges at several levels. First, the institutional structure of research in the UK seems not to be conducive to securing the coordination necessary for success, particularly in high technology and high value-added areas. The many stages that are necessary to link scientific research to development and commercial application require coordination between numerous actors, in the public, academic, and private sectors and, it is hypothesized, the UK has a weak framework for securing this coordination.

Diffusion of new technologies is slow and absorptive capacity appears weak, particularly in SMEs, often important parts of supply chains. Non-market sectors such as health care, education and government, are also challenged in connecting innovation and productivity. What are the factors creating this problem, to what extent are they related to weak vocational training, and can targeted business innovation approaches be designed and implemented?

There are large gaps in the understanding and measurement of knowledge capital and other types of intangible capital, whose economic properties differ from

those of tangible assets (Haskel and Westlake, 2018). Much work remains to be done in exploring the definition, measurement, and valuation of components of knowledge capital, as well as the interactions between intangible assets and organizational, human and social capital (Servaes and Tamayo, 2017).

### **Organizational Capital**

The UK has a distinctive business demography compared to European comparator countries. It has a small manufacturing sector accounting for less than 9 per cent of employment and containing relatively few internationally competitive firms. It is well represented in financial, legal and business services, creative sectors and education with the service sector accounting for 47 per cent of exports (Department for International Trade, 2020). It also has a relatively large personal services sector, including many small enterprises in accommodation, entertainment and catering. Relative to similar countries, there are few mid-sized companies, and there is a high turnover of firms with high average birth and death rates (Besley and Davies, 2019). Despite this turnover, there is a long tail of low-productivity firms (Haldane, 2018).

There are a number of broad challenges for research. The first surrounds the potential role of an industrial strategy in developing internationally competitive firms and clusters of strength in manufacturing and in knowledge-intensive high value-added areas. This is particularly so as the UK seeks to develop an activist industrial strategy after four decades of eschewing such policies. Another is to work with firms and fine granular data to identify the obsta-

cles to raising productivity in SMEs, and to design practical ways of raising performance. Are there significant barriers to entry, and perhaps more importantly, to the growth of firms from small to medium size? Is corporate governance conducive to such growth, or biased towards short-termism and against long-run firm strategy?

A further area relates to trade policy, particularly Brexit and the UK's evolving pattern of international trade agreements. These will change market conditions, will likely lead to changes in supply chains, and may have important implications for foreign direct investment. FDI has been important to the UK and is associated with higher productivity, both in the investing firm and through spillovers to other firms (Javorcik, 2004; ONS, 2017). Much of this is "export platform" FDI, intended to supply both the UK and the wider European market. It will be important to track the shocks that firms face and their responses to them, following Brexit as well as COVID-19.

## Geography and Place

UK productivity varies widely across regions (Zymek and Jones, 2020; McCann and Vorley, 2020; Haldane, 2018). These variations are large by international standards and, as well as dragging down measures of national productivity, create pockets of severe deprivation, social discontent, and political division. Some of the historical origins of this go back a very long way, others occurred during the upheavals and de-industrialization that took place in the 1970s and 1980s. The textbook economic adjustment mechanisms in response to negative regional shocks are out-migration of

workers, and inwards movement of replacement investment and jobs. These operated to a limited and imperfect extent, leaving many places in a low-level trap.

There are several aspects to understanding this. On the jobs side, we need to understand the location decisions of firms and the role of different factors – input costs, market access, skill availability, business ecosystem, etc. – in shaping location choices. What sort of jobs replace those that are lost following a negative shock? What are the local multipliers associated with different activities that may create spillovers and value for the region as a whole? The social and economic impact typically involves multiple mutually reinforcing processes, both economic and social. These include a low labour force participation rate, loss of skills, lower land and house prices, reduced building and infrastructure maintenance, and possible loss of tax base and deterioration of public services. The social implications of these changes transmit through several generations with devastating effects for attainment and for well-being.

Understanding regional productivity differentials raises numerous other questions. To what extent are measured productivity differences to do with physical productivity, or with regional variations in prices of non-traded outputs? The answer matters greatly for the design of policy. Why does the positive relationship between city size and productivity that holds in most countries break down in the UK? What does it take to detach firms from an existing cluster, and what are the costs, as well as the benefits of so doing?

Negative place-specific shocks have had

persistent effects despite substantial policy interventions. There are lessons to be learned concerning the effectiveness of local economic development strategies, infrastructure investment, land-use and housing policy, educational and social interventions, and perhaps above all, the interactions between these different interventions. The institutional framework is critical, with the hypothesis that UK structures inhibit local initiative. Government is highly-centralized, as are private sector services such as banking, while local business networks are in many places weak and do not provide an effective voice for job creation.

### **Macroeconomic Policies and Trends**

While, as described above, underinvestment in the three capital assets and the highly unequal distribution of those assets across regions and devolved nations are at the core of the UK productivity puzzle, the macroeconomic context is key to providing a supportive business and financial environment. This is, and will be, particularly true as we seek to understand the economic shock created by COVID-19 and formulate effective policies to restore economic growth and foster productivity.

The wider macro-economic research agenda will look at both private and public finance. From a private finance viewpoint, a large financing gap for business has emerged due to, amongst other things, credit shortages in the post-financial crisis period as banking restrictions on lending lead to shortfalls in productive investment (Chadha, 2017). Such frictions may have interacted with monetary policies to build up a mass of relatively unproductive firms,

many carrying historic debt that impedes future investment.

From a fiscal viewpoint, public investment in productivity enhancing infrastructure may be limited by the fiscal regime and accounting frameworks used by the Treasury, as well as by the decade of ‘austerity’ following the financial crisis. The politicization of public expenditure may also work against long-term planning. A longer run policy framework, as well as the development of institutional capability is the key to unlocking better growth prospects.

### **Governance and Institutions**

There are multiple aspects of the UK productivity puzzle that are deeply rooted in the underlying features and functioning of UK institutions and governance. There is a view that much decision making is too centralized spatially, and at the same time too fragmented functionally. Incentives of both politicians and officials are at times misaligned and inappropriate. And while some aspects of the regulatory system have evolved rapidly (e.g. in finance), others are ossified (e.g. land-use planning).

The geographical concentration of power in Whitehall and Westminster may stifle local initiative and pay insufficient attention to local circumstances. While there are moves to devolve power in the UK, there is a tension between devolution and the capacity of local areas to make and implement decisions, as well as questions about the shifting of power and resources. Identifying the appropriate spatial level requires understanding the complementarities between investments in human, knowledge, and organizational capital, and the best ways of supporting collaboration be-

tween local business, government and the educational sector. Institutions and governance arrangements are key to all these issues (Acemoglu and Robinson, 2012).

A common theme in much of the above is the failure to recognize, or internalize in decision making, the non-market interactions between those making the decisions and those affected by them (Rajan, 2019; Coyle, 2020). These interactions are essentially externalities, but in a much wider sense than economists' traditional use of that term. For example, in making decisions, businesses need to take account of implications for their supply chain, customers, workers and the community in which they are located. Development of an energy strategy – particularly during a period transition – requires coordination between producers, suppliers of infrastructure, producers of energy-using goods, and final consumers.

Even at the level of central government, policies tend to be functionally fragmented. For example, transport infrastructure decisions are made on a project-by-project basis, often not coordinated with implications for housing or jobs in affected areas. Education and human capital policies are rarely cognisant of policy priorities across government departments and between regional or local policy entities. Policies for vocational education and training, higher education and schools are all developed and delivered in different ways.

These institutional issues apply not only to government, but also to private sector activities. Finance is the most obvious, in which decision making is concentrated in the South East of the country, and has become divorced from 'on the ground' lo-

cal information (Mayer *et al.*, 2018). Elite educational institutions and the best-paid jobs for graduates are similarly concentrated in the East and South East of the country. The task for both researchers and policymakers is to understand – taking into account particular circumstances – how policy can be coordinated in order to boost productivity, and what institutional reforms are necessary to support policy coordination.

### **Social, Environmental and Technological Transitions**

Improving productivity may become even more challenging as the UK – like other advanced economies – needs to address major technological, societal and environmental transitions over the next decade (as well as nearer-term crises). While new technologies offer great potential for faster productivity growth, their slow and uneven adoption, as well as specific challenges such as cyber and data security, pose further productivity risks (Brynjolfsson *et al.*, 2019; Van Ark *et al.*, 2020).

From a productivity perspective, it is important to address the impacts of digital transitions on production, jobs and work: what are the productivity impacts across sectors, how is the quantity and quality of jobs affected, and how does the reskilling and training of employees interact with the absorptive capacity of firms for new technologies and innovations? Digital transformation also enables more efficient ICT-mediated business models in various sectors, including transport (smart mobility), energy and utilities (smart grids, IoT applications, etc.) and food and retailing (smart food labelling, online shopping, and

improved supply chain management).

Similarly, without co-ordinated activity the drive towards net-zero carbon emissions could be detrimental to productivity. At the positive end of the scale, green growth policies may contribute to shaping market frameworks and incentives such that net-zero carbon and high productivity are complementary. At the negative end, it appears that without significant interventions, low carbon technologies may raise cost and cause shifts to lower productive sectors and activities. There are key questions regarding the regulatory environment to induce productivity-enhancing investments. There are also important measurement issues related to the impact of “no-action” scenarios on productivity and economic welfare.

An ageing society, post-Brexit changes to trade networks and immigration, as well as growing inequality in people’s access to decent (and productive) work are among the other emerging threats. The long-run impact of COVID-19, on work habits, urban structure, supply chains, patterns of consumer expenditure, and on governments’ fiscal space remain to be seen.

### **Measurements and Methods**

Innovation in measurement and methods will be at the core of our research, and is cutting across the themes discussed above. There are conceptual issues to do with what is measured and how productivity measures are interpreted. Some of these are long-standing issues to do with externalities and non-market activity. Others have been thrown into sharp relief by recent events, such as Brexit and COVID-19. If a firm changes its production methods

to increase resilience then (even absent any externalities or non-market effects) how do we value this change in its measured productivity?

There are measurement issues, notably to do with productivity in service sectors, with regional price and productivity differentials, with measurement of intangible inputs and environmental capital, and, above all knowledge. There are new techniques and data sources that can greatly increase research capacity. These include increasing availability of administrative data, and multiple sources of “big-data” at granular levels of spatial and transactional detail.

### **Contours of the Engagement and Implementation Agenda**

There is no ‘silver bullet’ solution to the UK’s productivity puzzle. The Productivity Institute’s research priorities point at the need to remove the obstacles to chronic underinvestment, to tackle the fragmented decision making and lack of co-ordination of investments at all levels, and to reinvent the link between productivity, well-being and improved living standards. Productivity essentially arises from a combination of a mix of business innovation and management quality within firms, supply chains and eco-systems between firms, and an over-arching framework of institutions and governance structures, appropriately conditioned by local and regional economic and social conditions.

In the UK context, this means that the engagement and implementation activities of The Productivity Institute need a strong regional focus. The Institute will therefore establish eight Regional Productivity Forums that reach across the whole UK, in-

cluding the three devolved nations, to provide the route through which businesses, regional and local policy-makers and other stakeholders will engage in the work of the Institute.<sup>3</sup> These will be run out of the participating universities in each of the regions or devolved nations, and will have three main objectives:

- To work with target users to scope their needs and challenges, identifying where The Productivity Institute can best add value, in support of the Institute’s guidelines that the majority of its research activities and outputs will be developed in collaboration, and in some instances through co-production, with business and policy users.
- To help identify the key topics and issues that have important implications for regional productivity performance and where stakeholders can come together to debate the issues and identify solutions. This could include for example, economic recovery and growth plans, business support and innovation programmes, employment and skills programmes, social innovation programmes, or infrastructure and digital investment initiatives.
- To contribute to the setting of The Productivity Institute’s overall research agenda and, where relevant, individual projects that have a regional component. This will include initiating regional innovation projects and

developing proposals for larger scale projects that will be taken forward through the Institute’s research plans.

Insights from the Regional Productivity Forums will be documented and shared through The Productivity Institute’s Productivity Laboratory which may also support or initiate benchmarking, surveys or RCTs (randomly controlled experiments) working with multiple Regional Productivity Forums.

By no means does the strong regional focus of the Institute’s engagement programme mean there is no role for national policy initiatives that support productivity. The Productivity Institute will establish a National Productivity Council to develop and support the national debate on productivity. The Council’s focus will be on promoting robust and consistent policies to address the UK’s chronic productivity shortfall. It will operate as an academic forum consisting of researchers from a variety of disciplines to develop research-based policies, and establish and explain the policy implications of research produced by The Productivity Institute and elsewhere. It will also support the translation of the Institute’s regionally based insights into nationally coherent, coordinated and long-term policy responses.

While the National Productivity Council is independent from government, it will intensively engage with government and other national bodies (such as Innovate UK, and the Industrial Strategy Commis-

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<sup>3</sup> The Regional Productivity Forums will include Scotland, Wales and Northern Ireland and five regions in England, including the East, the Northeast/Yorkshire & Humberside, the Northwest, the Midlands, and London and the South. The forums will be chaired by a regional business leader and supported by a Regional Forum lead from each of the partner institutions.

sion). In this respect, the Council can become the focal point for Whitehall initiatives related to productivity issues, including agenda setting, informing policy-makers about the policy implications of their plans, and responding to policy requests. The Council, which will be run with the National Institute of Economic and Social Research, will look to highlight regional, national and international best practice, and identify and test models of researcher and policy-maker interaction such as issue-based task forces used by the Australian and New Zealand Productivity Commissions.

Finally, The Productivity Institute aims to be an open and transparent organization and will invite participation from researchers from across the UK and internationally. It operates a Productivity Fellowship program to support the exchange of ideas and collaborative research and engagement activities. This programme supports cross-institutional and cross-thematic research through several schemes including Productivity-in-Practice Business and Research fellowships joining business people and academics on specific projects; Policy Fellowships in the National Productivity Council; and short Career Development Secondment Programmes for business people, policy-makers and academics.

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# The Pandemic and Short-Run Changes in Output, Hours Worked and Labour Productivity: Canadian Evidence by Industry

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## ABSTRACT

The official measure of Canadian labour productivity rose by about 15 per cent (not annualized) during the first two quarters of 2020, reflecting a decline in total hours worked that exceeded an exceptional decline in output. We analyze this short-run change using monthly data disaggregated to 87 industries, focusing for analytical reasons on changes from April 2018 to April 2020 and August 2018 to August 2020. Just over one-fifth of the April labour productivity increase, and just under three-fifths of the smaller August increase, can be associated with the changing hours composition across industries. Estimated indices for the feasibility of working from home, the degree of worker health (COVID) risk, and the extent workers in the industry are customer-facing are not associated with the short-run changes in labour productivity by industry. However, there is clear evidence that industries with high work from home index values tended to have smaller reductions in output and hours.

As it has internationally, the COVID-19 crisis has had a massive and historically exceptional impact on the Canadian economy. Surprisingly, the crisis produced

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an immediate massive and unprecedented increase in measured labour productivity, as shown in Chart 1, where major economic downturns are shaded in grey and it can be seen in each other case that labour productivity actually fell. Specifically, the official Statistics Canada business sector productivity measure rose on a seasonally-adjusted basis by about 15 per cent from 2019Q4 to 2020Q2. However, far from being a sign of economic health, the sudden spike in labour productivity is the opposite. The COVID-19 pandemic appears to have caused a more than 15 per cent reduction in real business sector GDP over the same two-quarter period. However, total business sector labour hours fell by a much greater 28 per cent over that same period, resulting in the observed increase in labour productivity. Gu (2020) notes that a similar but smaller increase was already evident in first quarter 2020 data.

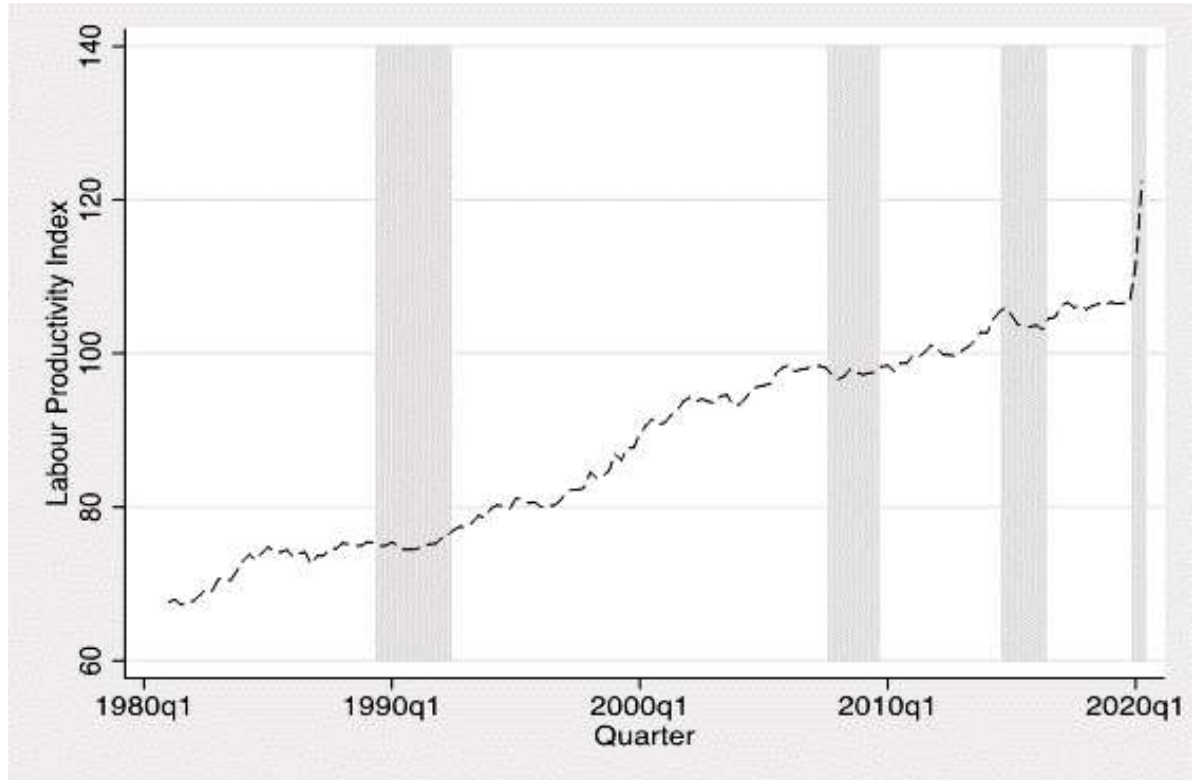
A number of labour market studies that have emerged since the beginning of the crisis are informative as to why hours worked fell more than real GDP. One key finding by Lemieux, Milligan, Schirle and Skuterud (2020) using Statistics Canada's Labour Force Survey data, was that the employment losses associated with the pandemic were disproportionately borne by those with low wages. This is at least a partial explanation for why total labour compensation per hour worked actually rose during the pandemic, by 20.3 per cent from 2019Q4 to 2020Q2, using data from the same Statistics Canada table as Chart 1. There was a compositional effect as workers with lower wages lost jobs and work hours disproportionately. This inequality-increasing loss of work is consistent with

the measured productivity rise (as lower wage workers also make smaller measured contributions to real GDP).

Following up on the Lemieux *et al.* (2020) study and other initial LFS studies such as Gallacher and Hossain (2020), in this article we incorporate changes in real GDP and hence investigate measured labour productivity. Because we want to capture the deepest point in the trough in April, 2020 as well as obtain some idea of the extent of recovery using the most recent data (August, 2020, as the 2020Q3 data are not yet available at time of writing), we somewhat unconventionally construct our estimates using monthly data. Second, we pursue an industry approach at a relatively fine disaggregation. This allows discussion of industry composition effects and also permits some investigation of how different industry characteristics may have mattered during the pandemic. Because some industries have both business and non-business sector elements, the non-business sector is included in this analysis.

We matched real GDP data to Labour Force Survey data using the North American Industry Classification System (NAICS) 3-digit level. We find that just over one-fifth of the estimated April, 2020 rise in labour productivity can be associated with changes in industry shares of hours worked (both from net job losses as well as from changes in hours among those who remain employed). The comparable fraction for the smaller increase in August, 2020 is just under three-fifths. We then use the O\*NET database to construct indices for three attributes of employment in each industry that may matter during the pandemic: the feasibility of working from

Chart 1: Business Sector Labour Productivity in Canada, 1980-2020



Note: Major economic downturns are shaded in grey.  
Source: Statistics Canada, Table 36-10-0206-01

home, the health (COVID) risk to workers, and the average degree to which persons employed in that industry face customers. We then explore how short-run changes in each industry's output, hours worked and productivity per labour hour are associated with the three indices.<sup>2</sup>

Of the three indices, we find that only the feasibility of working from home is clearly associated with changes in real GDP and hours worked: the greater the possibility of working from home, the less was the reduction in real GDP and hours worked so far during the pandemic. While this is not surprising, some of the labour mar-

ket studies (e.g. Gallacher and Hossain, 2020, who used 2-digit industries) found only weak evidence that the possibility of remote work was protective of employment. None to our knowledge extended the analysis to include real GDP or labour productivity. Our estimates do not indicate comparably strong relationships involving either the health risk or consumer facing indices. Changes in labour productivity as measured by real GDP to hours worked were not associated with any of the indices.

The first major section of the article will provide a very brief review of some of the recent and relevant literature. The second

<sup>2</sup> Blit (2020a) performs a related analysis, examining which Canadian industries have the highest health risk index and fraction of routine employment, to determine which industries are likely to experience the most automation (and hence the largest increases in long-run productivity) as a result of the COVID-19 crisis.

section will describe the analysis. The third section concludes.

## Recent Literature and Findings

In this section we provide a brief literature review that makes two essential points. First, the estimated rise in labour productivity is consistent with studies of the Canadian labour market that note that lower wage workers lost their jobs disproportionately with the pandemic. That literature also has discussed the association of job loss with working at home, one of the three factors we focus on in our discussion of industry productivity. Second, while there is so far relatively little in the literature relevant to the second factor we study, the COVID risk of working in an industry, there are some findings relevant to our third factor, the degree to which workers in the industry are customer facing. There is evidence that customer traffic fell even before government restrictions were introduced as well as evidence that customers were resistant to “facing” in certain industries.

Beginning with the labour market side, as noted, some of the earliest economic analysis of the pandemic was based on the Labour Force Survey (LFS), which is extremely timely, released within ten days of the end of the reference month. For ex-

ample, Lemieux *et al.* (2020) use the LFS to document that the COVID recession reduced the employment and total hours of low-wage workers much more than for workers with higher wages. Women, particularly those with younger children (see also Qian and Fuller, 2020) lost employment and hours disproportionately as did the young and those not in unions. The findings of Beland, Fakorede and Mikola (2020) and Mo, Cukier, Atputharajah, Boase and Hon (2020) for the self-employed and business owners are similar in that businesses owned by those in historically disadvantaged demographic groups appear to have been relatively harder hit.

Still more recent work from a large project, designed in part to guide economic reopening, finds more extensive evidence that the COVID recession has worsened income inequality, which again we note is consistent with real GDP not falling as much as hours worked (Baylis *et al.* 2020).

Hossain and Gallacher (2020), Deng, Morissette and Messacar (2020) and Jones, Lange, Riddell and Warman (2020) analyze the working from home aspect. The first two papers use the DN approach<sup>3</sup> (Dingel and Neiman, 2020) to find that about 40 per cent of jobs in Canada can be done remotely from the workplace.<sup>4</sup> Hossain and Gallacher (2020) find that workers are less

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3 The Dingel and Neiman approach established the usefulness of the O\*NET approach that we also use in our analysis. To give some examples of their classification rules, they classify an occupation as one that cannot be performed at home if respondents say on average that their job rarely uses email, involves violent people, is often outdoors, requires exposure to disease, entails frequent minor injuries such as burns or cuts, involves considerable walking, running, moving of objects or other physical activity, requires protective or safety equipment, requires machines besides computers, involves working directly with the public, or entails repairing, maintaining or inspecting equipment or structures.

4 It is perhaps interesting that these estimates are close to the pre-pandemic estimate of Chen and Mehdi (2019) that 41.5 per cent of jobs have significant flexibility in working hours, even though flexible working hours and working from home are different.

likely to have the possibility of working remotely if they are poor, male, in the private sector (especially in smaller firms), single, seasonal, contractual or part-time, younger, non-immigrant, and have no college degree. Deng *et al.* have similar findings. Working with industry data disaggregated by 2-digit NAICS code, Gallacher and Hossain (2020) find only relatively weak evidence of a relationship between the preservation of employment at COVID onset and their estimates of the average industry possibility of remote work.

Jones *et al.* (2020) emphasize vacancy data. They apply the DN method to National Occupation Classification at the 4-digit level and then aggregate to the 2-digit level using the 2016 Census. They find no evidence of more vacancies for jobs with higher remote work potential.

Still the importance of working from home has been documented.<sup>5</sup> The LFS for April 2020 reported that during the reference week of April 12-18, of the 12 million Canadians that were employed and working more than 50 per cent of their usual hours, 5 million worked mostly from home. That included 3.3 million workers who normally worked in a location other than their home. Savage and Turcotte (2020), using data from the Statistics Canada nationally-representative Canadian Perspectives Survey Series, find that in June 2020 about 22

per cent of Canadian workers were working from home.<sup>6</sup>

Another strand of the recent literature has tried to identify the degree to which the reduction in economic activity was due to regulation (“the government shut down the economy”) or to independent individual behavioural change (“the people shut down the economy”). For the United States, Goolsbee and Syverson (2020) used cell-phone tracking data to find that much of the economic decline preceded restrictions. Of the average 60 per cent decline in consumer traffic, they found that only 7 percentage points could be attributed to policy.

Armstrong, Lebo and Lucas (2020) examine data for 75 U.S. and Canadian cities and find that applicable regulations designed to reduce COVID spread were not dissimilar in extent and timing across the two countries. Hence differences in outcomes are plausibly driven by individual choices and not regulation. Consistent with this, Chan (2020) finds evidence for Canada of substantial social distancing prior to regulation.

Any attempt to disentangle the effects of government regulation from individual choices will be hampered by the identification problem that in Canada, imposed restrictions were similar and fairly synchronous across provinces. Moreover, it is

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<sup>5</sup> The distinction between “working remotely” and “working from home” is not always clear. Since we use the classification approach of Dingel and Neiman (2020) we adopt their terminology of feasibility of “working from home”. Among the variables that make up the index are variables such as whether a job is performed outside, that preclude working from home but do not necessarily preclude working remotely in a different outdoor location. When we refer to an article we use the term the authors most commonly use.

<sup>6</sup> Further, while we know of no comparable estimate for Canada, Barrero, Bloom and Davis (2020) estimate that after the COVID crisis, one in ten jobs (and 20 per cent of office jobs) will have permanently switched to work from home as part of very large predicted labour market changes, with 32 per cent to 42 per cent of COVID-induced layoffs permanent.

difficult to assess when and if regulations were binding. For example, it seems clear that the relaxation of regulations in summer 2020 did correspond to increased economic output in the restaurant sector but that does not imply that further relaxation (e.g. permitting closer tables) would expand output further.

With respect to consumer attitudes, Langevin and Turcotte (2020) analyze responses to questions from Statistics Canada's Canadian Perspectives Survey Series in June, 2020 and find that 38 per cent of individuals were very concerned about going to restaurants and bars while an additional 50 per cent were somewhat concerned. Further examples of the (very concerned, somewhat concerned) numbers were for mass events (66 per cent, 27 per cent), air travel (64 per cent, 30 per cent), shopping (24 per cent, 62 per cent) and personal care appointments (17 per cent, 57 per cent).<sup>7</sup> We can see these concerns reflected in the change in output in some of the industries we study. Still, as mentioned

and will be discussed further, we find no strong association between changes in either output or work hours and our index of customer facing. This is consistent with the view that the degree of customer facing does not matter as much as how essential the product is.

## Analysis of Industry Data

As has been mentioned, in order to study the trough of the spring COVID recession in April 2020 as well as to be able to study the extent of the recovery by August, 2020 (most recent data at time of writing), we use monthly data. No official monthly data on productivity are available and even the quarterly data are not available at the level of industry disaggregation that we use. For the labour productivity calculation, our numerator is real GDP by month and our denominator is total main job hours worked by industry.<sup>8</sup> Because the latter is not available on a seasonally adjusted basis we used non-seasonally adjusted data (for the numerator trading-day

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<sup>7</sup> Besides imposition of and relaxation of restrictions, the other major policy initiatives have been large expenditures on income support. These presumably have affected consumer expenditure by industry although Chetty *et al.* (2020) have found using data by county, industry, and income group that in the United States, high-income individuals initially largely saved their COVID-related transfer payments. (Low-income individuals increased their spending but very little of the increase flowed to businesses most affected by the COVID-19 shock.) While we know of no comparable analysis for Canada, we note that in Canada as in the United States, second quarter 2020 saving rates were both in excess of 25 per cent, a massive increase over their normal values of around 7 per cent or less.

<sup>8</sup> Real GDP estimates by industry, classified using North American Industrial Classification System (NAICS) 3-digit codes, are obtained from Statistics Canada, Table 36-10-0434-01. Total hours in main job were obtained from the LFS and are found in Table 14-10-0036-01, except the finer level of NAICS disaggregation which required access through the Statistics Canada's Real Time Remote Access (RTRA) system (<https://www.statcan.gc.ca/eng/rtra/rtra>). Matching the real GDP industry data by industry to the LFS industries requires a concordance to convert the Statistics Canada GDP industry codes to 2007 3-digit NAICS codes, available at: [https://www.statcan.gc.ca/eng/statistical-programs/document/1301\\_D2\\_V2](https://www.statcan.gc.ca/eng/statistical-programs/document/1301_D2_V2). The concordance of the 2007 and 2012 NAICS codes is available at: <https://www.statcan.gc.ca/eng/subjects/standard/naics/2012/concordances-2007-2012-2>. Note because the NAICS codes are virtually unchanged at the 3-digit level since 2007, the resulting classification is essentially the 2017 NAICS codes with a few small sub-aggregations required to fit the LFS. Also note there are aggregation issues given that real GDP estimates are chained (2012) dollars. Table 1 gives the aggregate results for the 87 industries.

The main job hours worked variable is the only industry allocation available in the Labour Force Survey. In the official productivity statistics, an estimate for all hours worked is made using unpublished historical data.

**Table 1: Estimates of Per Cent Change of Real GDP and Productivity as if Labour Productivities were Constant by Industry April 2018 to April 2020 and August 2018 to August 2020**

	Actual	As if Industry Labour Productivities Constant*
April 2018 to April 2020		
real GDP	-15.0	-26.1
hours worked	-29.2	-29.2
labour productivity	20.1	4.4
August 2018 to August 2020		
real GDP	-2.6	-5.0
hours worked	-8.1	-8.1
labour productivity	6.0	3.5

\*Assumes only the composition of hours worked by industry changed while measured labour productivity by industry remained unchanged. Therefore the value for the hours worked row is the actual change. The value for the labour productivity row is how much labour productivity would have changed if only the composition of hours worked had changed and not labour productivity by industry nor total hours worked.  
Source: Authors' calculations based on Statistics Canada data.

adjusted, the only non-seasonally adjusted option available). Following Lemieux, Milligan, Schirle and Skuterud (2020), we focus on April 2018 to April 2020 changes, skipping 2019 because the Labour Force Survey reference week for April, 2019 included Easter. For consistency, we also use August 2018 to August 2020 per cent changes. The use of April over April and August over August rates of change is intended to diminish the effects of seasonality.

As a validation exercise, we group our monthly data for April, May and June for both 2018 and 2020 and use our methods to estimate 2018Q2 to 2020Q2 per cent changes, which were -10.8 per cent for real GDP, -21.5 per cent for hours worked and 13.7 per cent for labour productivity. The Statistics Canada official estimates (Table 36-10-0206-01) were -15.2 per cent for real

GDP, -26.4 per cent for hours worked and 15.3 per cent for labour productivity. It is not surprising that our estimated magnitudes for changes in real GDP and hours are smaller than the official estimates, because our estimates are for the full economy and the official estimates are for the business sector, where the non-business sector has been substantially more stable.<sup>9</sup>

Table 1 shows that for our focus period, April, 2018 to April, 2020, the estimated per cent changes in real GDP were -15.0 per cent, for hours worked -29.2 per cent and for labour productivity 20.1 per cent. The table also shows a calculation in which it is assumed that productivity by industry is constant and only the composition of work hours by industry changed. This “as if” calculation identifies the separate effect of shifts in work hours to industries that were always more productive, as dis-

<sup>9</sup> The paper was completed before the 2020Q3 official productivity estimates were available but we note from their recent release that the 2018Q3 to 2020Q3 official increase in business sector labour productivity was 4.4 per cent, not too far from our August 2018 to August 2020 estimate for all-sector productivity of 6.0 per cent in Table 1, just as the 2018Q2 to 2020Q2 official value of 17.0 per cent is reasonably close to our 20.1 per cent in Table 1.

tinct from the influence of changes in productivity that occurred within industries. Under this “as if” scenario, output would have fallen by more than it actually did. Moreover, we can see that labour productivity would have increased by 4.4 percentage points from the compositional effect in changing hours worked by industry. This is just over one fifth of the actual change.

For August, the actual per cent changes in real GDP, hours worked and labour productivity are smaller, but the increase in measured labour productivity of 6.0 per cent is still substantial, where 3.5 percentage points, or about three-fifths of its total change, can be attributed to the compositional effect.

What might explain the rest? With these data we can only speculate but one possibility is compositional effects within industries (e.g. laying off office cleaners as work is shifted to home). Firms may also disproportionately lay off more poorly performing employees. Low productive firms may shut down and surviving firms may shut down their low productivity activities. Finally, firms may disproportionately lay off workers who make longer-term contributions (e.g. workers in product development) because the return to such activities is now more uncertain. Such a decision may have long-term negative effects on productivity growth.

## **Working from Home and Other Factors**

To conduct the remaining industry analysis, we constructed indices for feasibility of working from home, health (COVID) risks and customer facing, for all 87 NAICS 3-

digit industries (see Table 2 for the list of industries) for which we have monthly real GDP and aggregate hours worked. All three indices were constructed using the O\*NET database by generating an index for each occupation and then aggregating to obtain an industry-level index. In particular, we convert O\*NET’s 974 Standard Occupational Classification (SOC) occupations into 494 4-digit Canadian National Occupational Classification (NOC) occupations using a concordance developed by the Brookfield Institute. We then compute the index for each industry as a weighted average of the index for each occupation in that industry, where the weights are the fraction of workers in the industry that are employed in each occupation (these fractions are obtained from the 2016 Canadian Census of Population).

We construct our working from home index following Dingle and Neiman (2020) who draw on nine questions from O\*NET’s Work Context survey and eight questions from the Generalized Work Activities Survey. We obtain the estimate that overall, 41 per cent of all Canadian jobs can be feasibly performed from home, closely matching the results for similar exercises, including the original Dingle and Neiman (DN) calculation for the United States as well as the Gallacher and Hossain (2020) and Deng *et al.* (2020) calculations mentioned above for Canada.

Our health risk index measures the risk of communicable disease and is constructed following Blit (2020b). It draws on four questions from the O\*NET Work Context survey relating to whether the individual works in close proximity to others, how often they engage in face to face discussions,

**Table 2: Estimated Remote Work, Health Risk and Consumer Facing Values for 3-digit NAICS Industries in Canada**

NAICS code	NAICS title	Work from Home value and quartile		Health Risk value and quartile		Consumer Facing value and quartile	
113	Forestry and logging	0.152	1	0.273	1	0.347	1
114	Fishing, hunting and trapping	0.048	1	0.506	3	0.105	1
115	Support activities for agriculture and forestry	0.267	2	0.370	1	0.457	2
11A	Crop and animal production	0.455	3	0.357	1	0.351	1
211	Oil and gas extraction	0.509	3	0.425	1	0.426	2
212	Mining and quarrying (except oil and gas)	0.239	1	0.435	2	0.339	1
213	Support activities for mining, and oil and gas extraction	0.321	2	0.435	2	0.432	2
221	Utilities	0.497	3	0.467	3	0.455	2
230	Construction	0.172	1	0.461	3	0.443	2
311	Food manufacturing	0.195	1	0.424	1	0.364	1
312	Beverage and tobacco product manufacturing	0.334	2	0.423	1	0.462	2
31X	Textile, clothing and leather product manufacturing	0.244	1	0.428	1	0.312	1
321	Wood product manufacturing	0.189	1	0.405	1	0.284	1
322	Paper manufacturing	0.261	2	0.454	2	0.278	1
323	Printing and related support activities	0.484	3	0.435	2	0.436	2
324	Petroleum and coal product manufacturing	0.350	2	0.428	1	0.364	1
325	Chemical manufacturing	0.427	3	0.460	3	0.372	1
326	Plastics and rubber products manufacturing	0.246	1	0.441	2	0.302	1
327	Non-metallic mineral product manufacturing	0.273	2	0.410	1	0.417	2
331	Primary metal manufacturing	0.229	1	0.415	1	0.265	1
332	Fabricated metal product manufacturing	0.276	2	0.425	1	0.318	1
333	Machinery manufacturing	0.401	3	0.436	2	0.363	1
334	Computer and electronic product manufacturing	0.620	4	0.439	2	0.407	1
335	Electrical equipment, appliance and component manufacturing	0.475	3	0.450	2	0.398	1
336	Transportation equipment manufacturing	0.279	2	0.457	2	0.336	1
337	Furniture and related product manufacturing	0.256	2	0.457	2	0.386	1
339	Miscellaneous manufacturing	0.429	3	0.461	3	0.412	2
411	Farm product merchant wholesalers	0.465	3	0.423	1	0.561	3
412	Petroleum and petroleum products merchant wholesalers	0.557	4	0.412	1	0.579	3
413	Food, beverage and tobacco merchant wholesalers	0.412	3	0.439	2	0.598	3
414	Personal and household goods merchant wholesalers	0.616	4	0.461	3	0.643	4
415	Motor vehicle and motor vehicle parts and accessories merchant wholesalers	0.466	3	0.468	3	0.619	3
416	Building material and supplies merchant wholesalers	0.516	3	0.440	2	0.619	3
417	Machinery, equipment and supplies merchant wholesalers	0.654	4	0.448	2	0.595	3
418	Miscellaneous merchant wholesalers	0.477	3	0.431	1	0.570	3
441	Motor vehicle and parts dealers	0.375	3	0.509	3	0.628	3
442	Furniture and home furnishings stores	0.377	3	0.548	4	0.742	4
443	Electronics and appliance stores	0.404	3	0.547	4	0.743	4
444	Building material and garden equipment and supplies dealers	0.316	2	0.548	4	0.732	4
445	Food and beverage stores	0.267	2	0.594	4	0.746	4
446	Health and personal care stores	0.304	2	0.675	4	0.786	4
447	Gasoline stations	0.211	1	0.512	3	0.599	3
448	Clothing and clothing accessories stores	0.294	2	0.588	4	0.809	4
451	Sporting goods, hobby, book and music stores	0.319	2	0.586	4	0.798	4
452	General merchandise stores	0.293	2	0.585	4	0.748	4
453	Miscellaneous store retailers	0.359	2	0.562	4	0.756	4
454	Non-store retailers	0.545	4	0.474	3	0.680	4
481	Air transportation	0.267	2	0.533	4	0.766	4
482	Rail transportation	0.208	1	0.470	3	0.398	1
483	Water transportation	0.230	1	0.495	3	0.456	2
484	Truck transportation	0.193	1	0.282	1	0.573	3
486	Pipeline transportation	0.640	4	0.444	2	0.446	2
488	Support activities for transportation	0.425	3	0.423	1	0.556	2
48Z	Transit, ground passenger and scenic and sightseeing transportation	0.116	1	0.497	3	0.657	4
493	Warehousing and storage	0.402	3	0.424	1	0.461	2
49A	Postal service, couriers and messengers	0.315	2	0.413	1	0.543	2
511	Publishing industries	0.865	4	0.421	1	0.503	2
512	Motion picture and sound recording industries	0.478	3	0.484	3	0.543	2
515	Broadcasting (except Internet)	0.613	4	0.455	2	0.580	3
517	Telecommunications	0.701	4	0.445	2	0.610	3
518	Data processing, hosting, and related services	0.937	4	0.439	2	0.396	1

NAICS code	NAICS title	Work from Home value and quartile		Health Risk value and quartile		Consumer Facing value and quartile	
519	Other information services	0.589	4	0.591	4	0.632	3
524	Finance and insurance	0.961	4	0.478	3	0.710	4
52A	Financial investment services, funds and other financial vehicles	0.962	4	0.460	2	0.559	3
52X	Credit, intermediation and monetary authorities	0.970	4	0.458	2	0.604	3
531	Real estate	0.488	3	0.463	3	0.643	4
53B	Rental and leasing services and lessors of non-financial intangible assets (except copyrighted works)	0.329	2	0.483	3	0.634	3
541	Professional, scientific and technical services	0.851	4	0.446	2	0.518	2
561	Administrative and support services	0.361	3	0.460	2	0.506	2
562	Waste management and remediation services	0.216	1	0.392	1	0.441	2
611	Educational services	0.814	4	0.590	4	0.496	2
621	Ambulatory health care services	0.218	1	0.742	4	0.713	4
622	Hospitals	0.225	1	0.734	4	0.669	4
623	Nursing and residential care facilities	0.213	1	0.669	4	0.600	3
624	Social Assistance	0.266	2	0.576	4	0.491	2
713	Amusement, gambling and recreation industries	0.254	2	0.550	4	0.617	3
71A	Performing arts, spectator sports and related industries, and heritage institutions	0.526	4	0.441	2	0.513	2
721	Accommodation services	0.118	1	0.544	4	0.641	4
722	Food services and drinking places	0.057	1	0.606	4	0.715	4
811	Repair and maintenance	0.157	1	0.417	1	0.389	1
812	Personal and laundry services	0.136	1	0.706	4	0.740	4
813	Religious, grant-making, civic, and professional and similar organizations	0.705	4	0.520	3	0.636	3
814	Private households	0.310	2	0.594	4	0.308	1
911	Federal government public administration	0.655	4	0.484	3	0.611	3
912	Provincial and territorial public administration	0.672	4	0.508	3	0.640	4
913	Local, municipal and regional public administration	0.372	3	0.500	3	0.631	3
914	Aboriginal public administration	0.579	4	0.494	3	0.608	3
Simple average of all industries		0.405		0.482		0.530	

Source: Author's calculations using 2016 Canadian Census for Population using O\*Net data and the Brookfield crosswalk as described in Vu (2019).

how often their job exposes them to disease/infections, and whether they (do not) work outdoors. For each question, each occupation is assigned a percentile rank relative to the other 973 occupations. The index for an occupation is then constructed as the average of its four percentile ranks.

Lastly, our customer facing index is constructed by the occupation's percentile rank on average responses to the question "How important it is to work with external customers or the public in this job" where arguably this will in most cases imply face to face contact.

Our index values are reported in Table 2. In each case they are reported along with their quartile position for that index, so that for example 114, fishing, hunting

and trapping, is in the first quartile for work from home (meaning it is difficult to work from home), the 3rd quartile for health risk (as many of those in the fishing industry work in close proximity with others), and in the first quartile for consumer facing (meaning little direct contact with customers).

Table 3 re-organizes a fraction of the above information by reporting the top 5 and bottom five values for each category. The results seem intuitive. For example, forestry and logging have low health risk from communicable disease such as COVID while the health care industries have a high risk. Note that the four types of manufacturing listed in the bottom five of customer facing are representative of many

**Table 3: Bottom and Top 5 Values for Work from Home, Health Risk from COVID and Customer Facing by 3-digit Industry**

<b>Bottom five values, Work from Home</b>		
114	Fishing, hunting and trapping	0.048
722	Food services and drinking places	0.057
48Z	Transit, ground passenger and scenic and sightseeing transportation	0.116
721	Accommodation services	0.118
812	Personal and laundry services	0.136
<b>Top five values, Work from Home</b>		
511	Publishing industries	0.865
518	Data processing, hosting, and related services	0.937
524	Finance and insurance	0.961
52A	Financial investment services, funds and other financial vehicles	0.962
52X	Credit, intermediation and monetary authorities	0.970
<b>Bottom five values, Health Risk from COVID</b>		
113	Forestry and logging	0.273
484	Truck transportation	0.282
11A	Crop and animal production	0.357
115	Support activities for agriculture and forestry	0.370
562	Waste management and remediation services	0.392
<b>Top five values, Health Risk from COVID</b>		
623	Nursing and residential care facilities	0.669
446	Health and personal care stores	0.675
812	Personal and laundry services	0.706
622	Hospitals	0.734
621	Ambulatory health care services	0.742
<b>Bottom five values, Customer Facing</b>		
114	Fishing, hunting and trapping	0.105
331	Primary metal manufacturing	0.265
322	Paper manufacturing	0.278
321	Wood product manufacturing	0.284
326	Plastics and rubber products manufacturing	0.302
<b>Top five values, Consumer Facing</b>		
453	Miscellaneous store retailers	0.756
481	Air transportation	0.766
446	Health and personal care stores	0.786
451	Sporting goods, hobby, book and music stores	0.798
448	Clothing and clothing accessories stores	0.809

Source: Based on Table 2.

other types of manufacturing that featured at the bottom of the list with values only slightly higher.

Table 4 presents the per cent changes from April 2018 to April 2020 and from August 2018 to August 2020 for each of the quartiles of work from home, health risk and consumer facing.

For real GDP, there only appears to be a recognizable pattern in the case of Work from Home. The reductions tend to be smaller for industries with higher feasibility of working from home, with a reduc-

tion of only 9 per cent for the quartile with highest work from home, by far the smallest April output loss. For the smaller August real GDP losses, it also appears that the reductions were less substantial in industries with high work from home indices. There are no other output patterns for the other categories, although the most substantial April output reduction was for the high health risk quartile, and this in spite of many health sectors (where health risks are highest) having expanded due to the health nature of the crisis.

**Table 4: Per Cent Changes in Real GDP, Hours Worked and Measured Labour Productivity By Estimated Work from Home, Health Risk and Customer Facing Industry Quartiles, April 2018 to April 2020 and August 2018 to August 2020**

Quartile	Work from Home		Health Risk		Customer Facing	
	April	August	April	August	April	August
<b>Real GDP</b>						
1	-29	-10	-16	-2	-25	-8
2	-32	-10	-24	-10	-19	-6
3	-20	-1	-17	-1	-17	-1
4	-9	-1	-35	-10	-30	-7
<b>Hours Worked</b>						
1	-37	-9	-25	-2	-25	1
2	-31	-10	-26	-6	-27	-14
3	-28	-12	-23	-6	-28	-7
4	-18	0	-42	-17	-36	-11
<b>Labour Productivity</b>						
1	21	4	20	6	10	-5
2	5	0	9	-1	15	15
3	16	16	12	10	21	11
4	18	4	18	9	13	4

Note: For work from home, industries in quartile 1 have the lowest per cent of workers that can work from home and quartile 4 has the highest. For health risk, industries in quartile 1 have the lowest average health risk from COVID and quartile 4 has the highest. For customer facing, industries in quartile 1 have the lowest per cent of customer facing workers and Quartile 4 has the highest.

Source: Authors' calculations.

For hours worked, the April pattern for work from home is clear, with smaller reductions in hours for the quartiles where working from home is more feasible. For August, the top quartile had no reduction in hours worked, although there is no real pattern otherwise. The high health risk quartile had a big percentage hours worked reduction in April, and health risk does appear to be inversely associated with hours worked reductions in August. There is also a weak indication that customer facing may have been associated with hours worked reductions in April, although less so by August.

With declines in real GDP and hours worked by industry both falling as the feasibility of work from home rises, and little pattern for the other categories, it is not surprising that there is no clear pattern for labour productivity. There is no evidence

that the industry-by-industry variation is related to work from home, health risk or the extent to which workers in the industry are consumer facing.

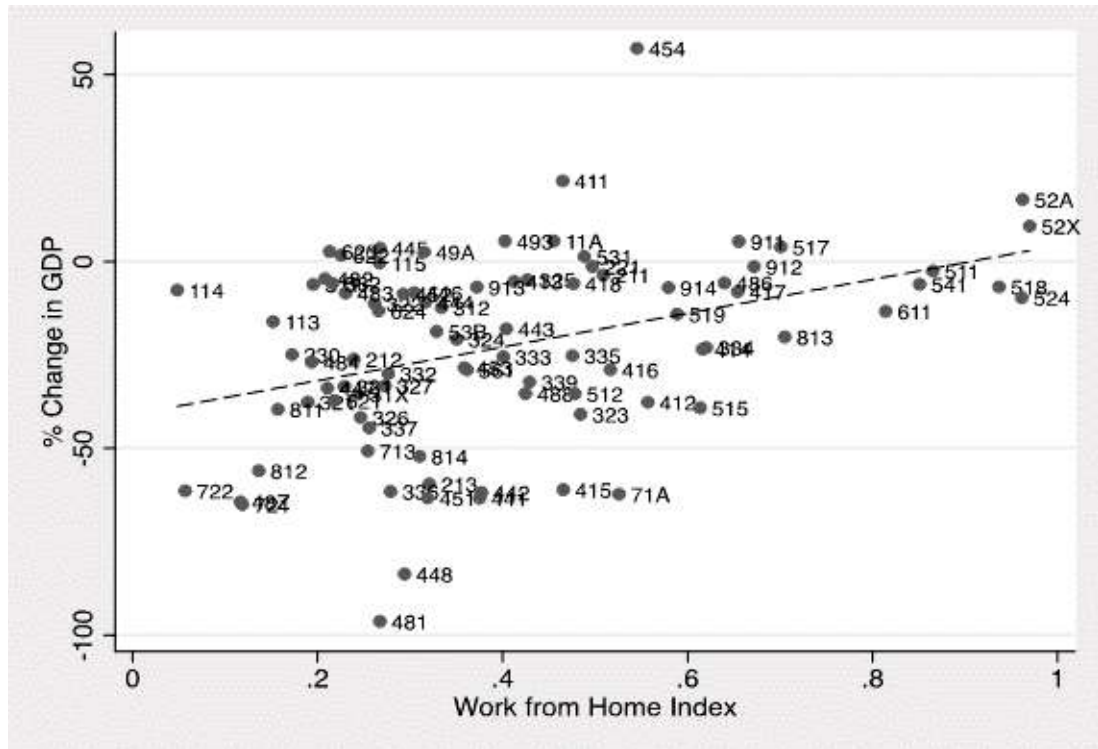
## Plots and Description Regressions

Another way to look at these results is to examine the scatterplots. Because there are 3 measures, real GDP, hours worked and labour productivity, and three factors, work from home, health risk and consumer-facing, there are three multiplied by three or nine scatterplots for each of the two months, and hence 18 scatterplots in total. While these are available on request to the authors, for brevity here we present only two, for the change in real GDP for April and August against our work from home Index.

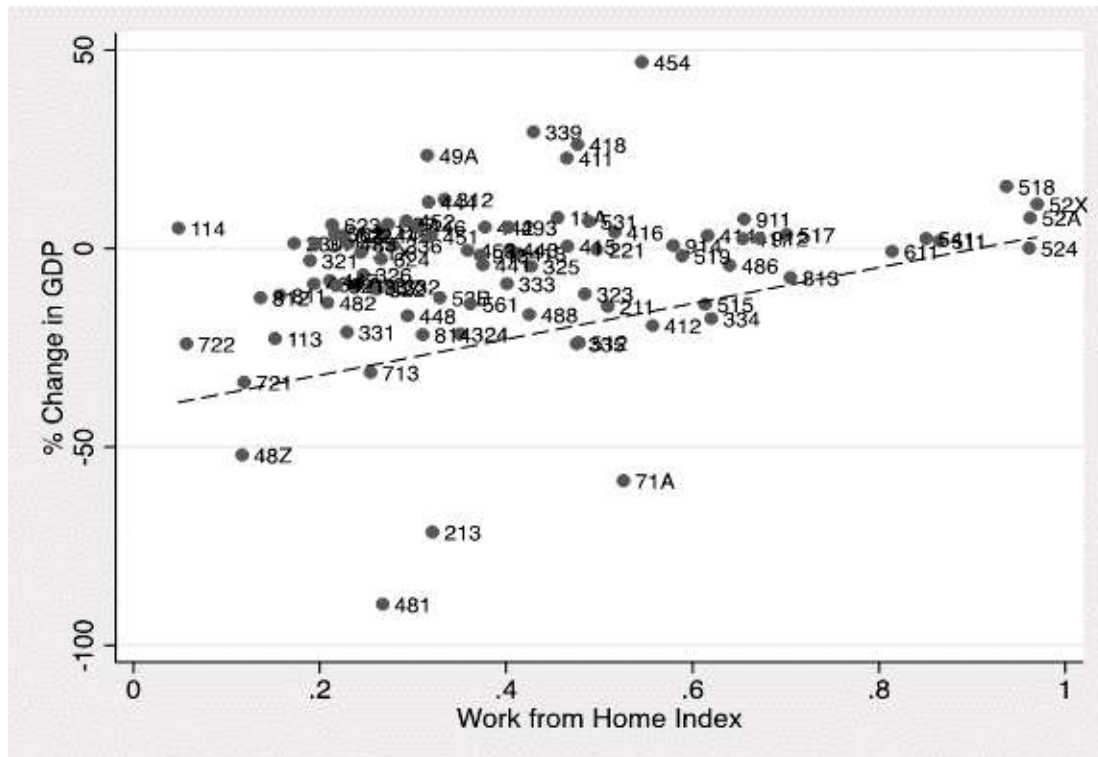
Again there is evidence of a positive association between changes in real GDP and

Chart 2: Scatterplots of Per Cent Change in Real GDP against Work from Home Index by 3-digit NAICS Industry

Panel A: April 2018 to April 2020



Panel B: August 2018 to August 2020



**Table 5: Descriptive Multivariate Regression Results for Dependent Variables Real GDP, Hours Worked and Labour Productivity and Independent Variables Indices of Work from Home, Health Risk and Customer Facing**

	GDP		Hours Worked		Labour Productivity	
	April	August	April	August	April	August
Work from Home	47.1*** (12.4)	24.2** (10.0)	46.2*** (12.3)	26.0** (11.4)	0.4 (18.9)	2.5 (15.8)
Health Risk	-9.2 (38.0)	8.4 (30.6)	-15.9 (37.4)	-9.9 (34.7)	45.8 (57.7)	25.8 (48.2)
Customer Facing	-23.7 (21.2)	-4.6 (17.1)	-25.8 (20.9)	-27.1 (19.4)	-20.6 (32.2)	7.8 (26.9)
Constant	-24.7 (16.4)	-16.8 (13.2)	-26.5 (16.1)	0.96 (14.9)	3.4 (24.9)	-11.5 (20.8)
$R^2$	0.17	0.07	0.18	0.10	0.01	0.01

Standard errors in parentheses. Statistically significant at the 5 per cent level (\*\*) and at the 1 per cent level (\*\*\*). Source: Authors' calculations.

our work from home index, with a stronger relationship in April than in August. We notice that industries that had high work from home values and no or small real GDP reductions include 518 (data processing, hosting, and related services), 52A (financial investment services, funds and other financial vehicles) and 52X (credit intermediation and monetary authorities). 48Z (transit, ground passenger, scenic and sightseeing transportation) and 722 (food services and drinking places) are examples with low work from home values and large drops in real GDP.

While as mentioned the other scatterplots are not reproduced here, we can report that the hours/work from home scatterplots are fairly similar to the scatterplots above, with the other scatterplots much flatter. In particular the labour productivity plots are almost level.

As a final way to present this information, we present the results of descriptive multivariate regressions with all three of our indices on the right-hand-side. These are sometimes called “horse-race” regres-

sions to convey the idea that while not necessarily having a causal interpretation, they do identify which variable has the strongest partial correlation with the dependent variable conditioning upon the remaining variables. Table 5 reinforces our finding of the relative empirical importance of work from home, as only its coefficients have conventional statistical significance in this context, and then only for the real GDP and hours worked equations. The work from home coefficients in both cases fall by about half from April to August. There is no statistically significant coefficient in the labour productivity regressions. Weighted regressions using February 2020 employment as weights are not presented but give very similar results.

## Conclusion

The Canadian economy experienced a striking increase in the real GDP to hours worked ratio, a measure of the change in short-run labour productivity, during the first months of the COVID-19 pandemic. We suggest that this increase is at least

partially due to a disproportionate reduction in work hours by those with low wages, as supported for example by the evidence of Lemieux *et al.* (2020). As such individuals will also tend to make smaller measured contributions to real GDP, their employment hour losses have through a compositional effect raised real GDP per hour worked.

We augment these empirical analyses of the impact of the COVID-19 pandemic on the Canadian labour market based on the Labour Force Survey with an exploratory analysis that incorporates changes in real GDP and hence can examine labour productivity. We disaggregate to 87 industries and for analytical reasons focus on per cent changes from April 2018 to April 2020 and from August 2018 to August 2020. We find that the compositional effects across industries can account for about 4.4 percentage points of a 20.1 percentage point labour productivity increase in April, that is just over one-fifth, and 3.5 percentage points of a 6.0 percentage point increase in August, or just under three-fifths.

We also create indices for the 87 industries to estimate the feasibility of working from home, average health risk (from communicable disease) and the average degree to which jobs in the industry are consumer facing. Our examination of NAICS 3-digit industry data suggests that of the three indices we examined, the strongest association with changes in output and hours worked was the feasibility of working from home: industries where working from home was more possible fared much better. While now familiar, in retrospect the rapid economic transformation associated with the conversion to work from home was re-

markable and it is clearly an important factor in the differential, inequality-increasing economic impact of the pandemic on individuals.

The changes in output and the changes in hours did not have as clear associations with the health risk index, even though the estimated associations were negative as expected. The lack of a strong relationship can in part be explained by the fact that two of the five industries with the highest health risk index (622 (hospitals) and 623 (nursing and residential care facilities)) were relatively unaffected because while some of their activities suffered, COVID-19 related activities expanded.

The changes in output and the changes in hours were negatively associated with the customer facing index, but again this includes a mix of “essential” and “nonessential” activities so it is perhaps not surprising that the estimated association is weak. In any case, we cannot in these data identify whether the association we observe is a consequence of government restrictions or independent, individual action.

In terms of labour productivity, we find that the industry composition effects are important, but there is no evidence of association with the industry characteristics that we expected to have mattered most during the COVID-19 crisis. More broadly, as the normal argument is that constraints such as those associated with COVID-19, either imposed by governments or individuals themselves, are unlikely to increase productivity, perhaps the measured productivity increases so far can best be taken as reassurance that the underlying, unmeasured losses have been so far limited. Yet while productivity as measured by output

per hour worked has increased, output per capita has clearly fallen, and improvements in that indicator are likely only attainable with continued increases in hours of employment.

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# Industry Productivity Performance in G7 Countries after the Global Financial Crisis: A Canadian Perspective

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## ABSTRACT

Compared to other G7 countries, Canada performed relatively well after the global financial crisis in both aggregate labour productivity and multifactor productivity (MFP) growth, which is in sharp contrast to its relatively weak performance in the 2000s. The objective of this article is to analyse the sources of Canada's superior performance by comparing it to other G7 countries. In particular, the article examines industry productivity performance, estimates the contribution of individual industries to both aggregate labour productivity and MFP growth, and highlights the differences between Canada and other G7 countries before and after 2010. To this end, this article develops a methodology to more precisely identify the underlying forces at the industry level that have either propelled or hindered productivity growth, and thereby identify which industries have been at the heart of the changes in productivity performance.

Canada's weaker productivity growth in the post-2000 period and compared to other G7 countries, especially the United States, has been subject to an extensive research (e.g. Tang, 2014 and 2017, and more recently Gu and Willox, 2018, and Sharpe and Tsang, 2018). Canada under-

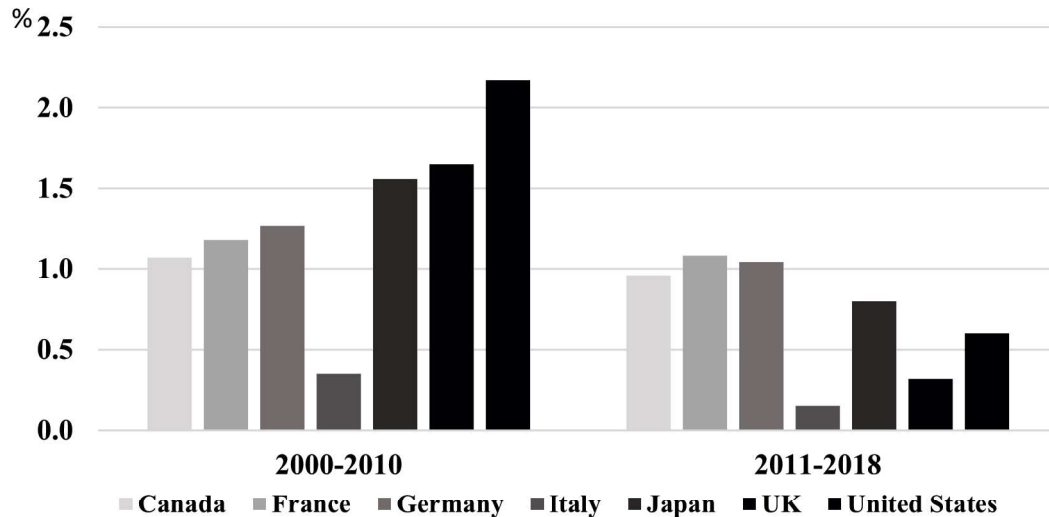
performed most of the OECD countries in productivity growth in the first decade after 2000. Among G7 countries, Canada's average annual aggregate labour productivity (real GDP per hour worked) growth rate over the periods of 2000-2010 was the second lowest at 1.07 per cent per year, only

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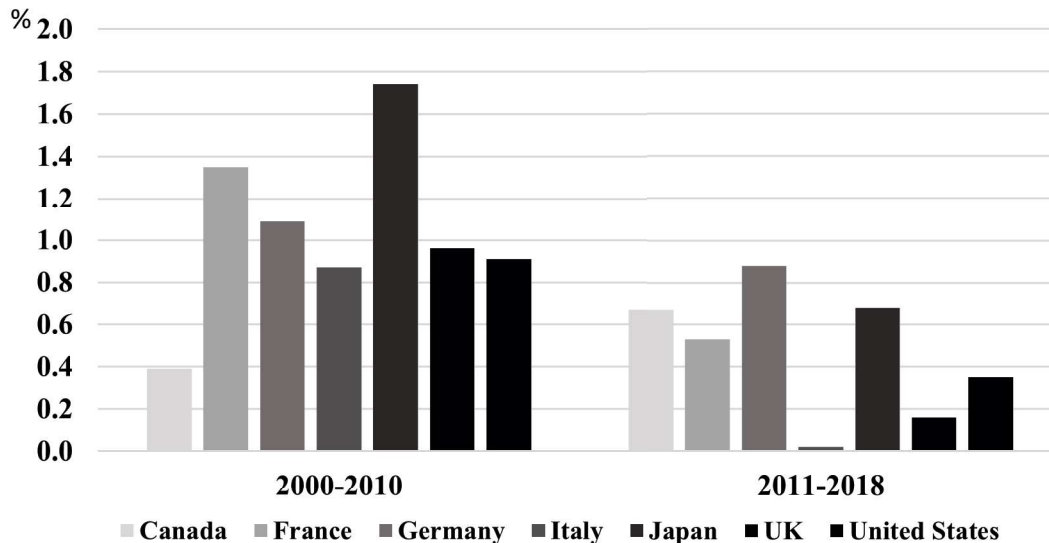
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Chart 1: Total Economy Productivity Growth in G7 Countries, 2000-2010 and 2011-2018 (per cent per year)

Panel A: Labour Productivity



Panel B: Multifactor Productivity



Source: OECD Productivity Data

ahead of Italy, and significantly lower than that for Japan (1.56 per cent), the United Kingdom (1.65 per cent) and the United States (2.17 per cent) (Chart 1, Panel A).<sup>2</sup> Also, Canada’s average aggregate multifactor productivity (MFP) growth rate over

the same period was the lowest and lagged significantly behind the other G7 countries (Chart 1, Panel B).

After recovering from the global financial crisis, however, Canada has emerged to become one of the leaders in produc-

<sup>2</sup> The growth rate for a period is the average of the annual growth rates over the period.

<sup>3</sup> Note that Canada’s relatively better productivity growth is sensitive to the period in question. For example, Canada was not one of the best productivity growth performers among G7 countries in 2015-2018. Also note that in this article we focus on productivity growth, not productivity levels. In terms of the total economy productivity level (output per hour), Canada still lags behind five G7 countries, only ahead of Japan.

tivity growth among G7 countries, at least up to 2018.<sup>3</sup> Canada was the third highest in labour productivity growth and the second highest in MFP growth (Chart 1). Over the 2011-2018 period, Canada experienced a 0.11 percentage points reduction in total economy labour productivity growth compared to the rate in 2000-2010, and the reduction was the second smallest after France (-0.10 percentage points). Canada was the only country that accelerated its MFP growth in 2011-2018 relative to 2000-2010 (0.28 percentage points), compared to MFP growth falls in other G7 countries ranging from -0.21 percentage points (Germany) to -1.06 percentage points (Japan).

Thus, Canada's improvement in its relative position in productivity growth performance among G7 countries between those two periods was on one hand due to Canada's persistent ability to maintain labour productivity growth or improve MFP growth after the global financial crisis. On the other hand, it was due to the slowdown in both labour productivity and MFP growth in other G7 countries. The decline in the United States, the leader of the labour productivity growth over the 2000-2010, was especially compelling. Labour productivity and MFP growth rates in the United States decreased from 2.17 and 0.91 per cent per year in 2000-2010 to 0.60 and 0.35 per cent per year in 2011-2018, respectively.

Productivity advance is the key for eco-

nomie growth and for the improvement in living standards. There are also other advantages for a country to improve its productivity relative to other countries. As higher productivity growth in a country raises the real income of the country's citizens at a faster pace than those in other countries, it helps to attract and retain capital and skilled labour in the country as factors of production become increasingly footloose in the globalized economy. This can create a virtuous cycle for productivity and economic growth.

For Canadian policy development to further improve productivity, it is important to better understand the differences of the sources or components of productivity growth between Canada and other countries.

The objective of this article is to examine what are the driving forces for Canada's relatively better productivity growth performance after 2010 with a comparison to other G7 countries.<sup>4</sup> To this end, building on our earlier research, we use a methodology that is able to more precisely identify the industries and the underlying forces or components that have either propelled or hindered productivity growth, and to observe which industries have been at the heart of the changes in productivity performance.<sup>5</sup>

Our methodology requires data for the G7 economies at the industry level. To ensure comparability, such industry-level

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4 We choose 2010 as the break year since most of the countries had re-established their economies following the crisis only after 2010. Note, however, that when 2009 is used, Canada still improved substantially its productivity growth position among G7 countries in 2009-2018 (or 2010-2018) compared to in 2000-2008.

5 Note that this article only studies industry performance and contributions to aggregate productivity growth. It does not attempt to examine factors driving industry performance. For such studies, see Sharpe and Tsang (2018), Gu (2019), and Tang *et al.* (2020).

data need to be developed consistently. Thus, in this article, we use KLEMS data, which will be discussed in detail later on. At the time of writing, the latest year for which data were available for all G7 countries was 2015, and thus our analysis at the industry level must end in 2015. Using the data, we estimate the contribution and the components of these contributions of individual industry to both aggregate labour productivity and MFP growth and highlight the differences that have emerged between Canada and other G7 countries in 2000-2010 and 2011-2015.

The findings in this article will contribute to a better understanding of Canada's relatively improved position in productivity growth performance after the global financial crisis compared to the other G7 countries.

This article is divided into four main sections. Section one explains the methodology used to decompose labour productivity and multifactor productivity into three components, within-industry productivity effects, price effects and size effects. Section two presents the empirical results for G7 countries for the 2000-2010 and 2011-2015 periods. Section three discusses the results in more depth for three industries: mining and quarrying, and manufacturing. The fourth and final section concludes.

## Methodology

The aggregate productivity performance of an economy depends on productivity

growth by industry and changes in industrial structure as well. In Appendix A, we set up an analytical framework to trace a change in aggregate productivity growth to the corresponding changes at an industry level. We build on the decomposition method originally developed by Tang and Wang (2004), which has been followed up by Diewert (2015), Tang and Wang (2015), and Zhao and Tang (2015).<sup>6</sup>

For both labour productivity and MFP, output at the aggregate level is value added while at the industry level, it is gross output. This means that to estimate industry contribution to aggregate productivity, we have to "peel" off the effect of intermediate inputs.<sup>7</sup>

## Decomposing Aggregate Labour Productivity Growth

In the Appendix, we show that an industry affects the aggregate labour productivity level through three channels. The first two channels are the industry own labour productivity level and the relative gross output price, which are partly offset by intermediate input intensity and the relative intermediate input price. The third channel is the size of the industry in the economy, which is indicated by the industry's share of total hours worked. This is consistent with the literature where the labour share is often used for aggregating labour productivity from the industry level.

A higher relative price of an industry's

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6 A theoretical and empirical justification of the Tang-Wang method is provided by Dumagan (2013).

7 When output at the industry level is also value added, the framework will be the same but without the terms associated with intermediate inputs. It is much simpler.

gross output, after the offsetting effect of the relative price of intermediate goods, positively contributes to aggregate labour productivity.<sup>8</sup> Equally, a lower relative price of an industry's gross output contributes negatively to aggregate productivity. Prices represent the ability of the industry to generate economic value in the economy. This is consistent with the chained-Fisher index in aggregation, which gives a greater weight to the industries with higher output prices. The chain-Fisher index has been adopted by many statistics agencies around world for real GDP estimation, including those in G7 countries.<sup>9</sup>

In terms of growth, we show that an industry can contribute positively to aggregate labour productivity growth through three channels: an improvement in its gross output labour productivity, a rise in its relative gross output price, and an increase in its share of total hours worked. This can be partly offset by the effect of the changes associated with intermediate input intensity, relative intermediate input prices and the labour input share. The “peeling-off” of the effects from intermediate inputs is necessary as output at the aggregate level is in value added while it is gross output at the industry level.

The contributions of the industry associated with gross output are weighted by the ratio of the industry's nominal gross output to nominal GDP in the period. Similarly, the effects associated with intermediate inputs are weighted by the ratio of the industry's nominal intermediate inputs to nominal GDP at the initial period. The weights are analogous to the “Domar weights” used to aggregate industry multifactor productivity growth calculated based on the gross output concept. Domar weights were originated by Domar (1961). They are the ratios of industry's current dollar gross output divided by aggregate value added in current dollars. The weights sum to more than one, reflecting the integration across industries. They have been widely used to aggregate gross output-based productivity at the industry level to value added-based productivity at the business sector or the economy level.

There are four components in the decomposing of aggregate labour productivity growth. The first component is called the productivity effect, or the within-industry productivity effect, as it is an industry contribution to aggregate labour productivity growth from the industry's labour productivity improvement after controlling for the

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8 The price effect is the effect from changes in the industry price relative to the aggregate price. It is not necessarily zero for three reasons. First, the price effect is a weighted sum. Second, the sum of the change in industry relative price is not by definition equal to zero. According to our formulation in the Appendix, the aggregate price is a value added price while industry price is a gross output price. The aggregate price is implicitly a chain-Fisher index of industry value added prices. Third, the price effect is also complicated by “peeling off” the effect from the change in the relative intermediate input price.

9 There is no standard approach to decompose aggregate productivity growth. Some economists argue that there should be no price effect related to industry contributions to aggregate productivity growth (e.g. Reinsdorf, 2015). They point out that the inclusion of relative prices effects in industry contribution to aggregate productivity growth, even though they are offsetting, can result in industries with large increases in prices making a large contribution to aggregate productivity growth, even though within-industry productivity growth may have been negative as in the oil and gas industry. Equally, industries with very large decreases in relative prices caused by very large within-industry productivity gains, can make a negative contribution to aggregate productivity growth.

effect from the change in the intermediate input intensity of the industry. Similarly, the second component is called the price effect as it is associated with the improvement in the relative gross output price of the industry after controlling for the effect from a change in its real intermediate input price. The effect captures the industry's ability in creating economic value. The third component is called the size effect as for aggregate labour productivity, the labour share indicates the industry size relative to other industries. The last component captures the interactions between the first three components. It tends to be small as it consists of second-order effects.

The framework used in this article is an extension of Tang and Wang (2004, 2015) as the decomposition here separates the effects from changes in relative prices and hours shares. It is an extension of Diewert (2015) from a value added framework to a gross output framework.

### **Decomposing Aggregate MFP Growth**

Labour productivity is only a partial indicator of productivity, which can be influenced by capital intensity and intermediate input intensity. To study the overall productivity performance associated with labour, capital, and intermediate inputs, the analytical framework for labour productivity growth by Tang and Wang (2004, 2015) can also be modified and extended for studying MFP growth.

As in labour productivity, the formulation in the Appendix shows that an industry can contribute to aggregate MFP level through three channels. The first two channels are industry own MFP per-

formance and the ratio of industry relative output prices to industry relative input prices, which is partly offset by the industry's intermediate input intensity (in all inputs) and the ratio of industry intermediate input prices to industry total input prices. The third channel is the relative size of the industry in the economy, which is indicated by the ratio of industry total input cost to aggregate total input cost. This is equivalent to the ratio of industry nominal gross output to aggregate GDP since nominal gross output equals total input cost at the industry level and nominal value added (or GDP) equals total aggregate total input cost at the aggregate level.

The format of the formulation for industry effects on aggregate MFP growth is the same as that for aggregate labour productivity growth. An industry can contribute to aggregate MFP growth by improving its own MFP, raising its output price relative to the total input price, and increasing its relative size in terms of nominal output. The contributions are partly offset by the corresponding effects associated with intermediate input use. As in labour productivity, here we designate the first component the productivity effect, or the within-industry productivity effect. This is the industry's contribution to aggregate MFP growth from its MFP improvement after controlling for any change in intermediate input intensity. Similarly, we designate the second component as the price effect as it is associated with the improvement in the relative gross output price of the industry after controlling for any change in its relative intermediate input prices. The third component is called the size effect as for aggregate MFP, the ratio of total industry in-

put cost to total aggregate input cost indicates the industry size relative to other industries. The last component captures the interactions between the first three components. It tends to be small as it consists of second-order effects.

Again, the decomposition framework for MFP is an extension of Diewert (2015) from industry output in value added terms to industry output in gross output terms.

## Empirical Results

Using the framework outlined above, we now estimate the industry contribution to aggregate productivity growth in Canada, with a comparison to other G7 countries. We first describe the data sources and then discuss the empirical results. We highlight the industries that either propelled or hindered aggregate productivity growth.

### Data

The application of our methodology for the estimation of industry contributions and the contribution components to aggregate productivity growth in an economy requires output data at the industry level. To this end, we extract the necessary data for our analysis from Statistics Canada for Canada, from the Institute of Economic Research at Hitotsubashi University for Japan, and from either the EU KLEMS or the World KLEMS databases for France, Germany, Italy, the United Kingdom and the United States.

These databases are made publicly available through the World KLEMS initiative based on Harvard University, and were supported by the EU KLEMS program based at the Groningen Growth and Development Center at the University of Groningen.<sup>10</sup>

The databases are fairly comparable and consistently developed. They allow for reliable comparisons in industrial structure and sources of productivity growth among G7 countries.

For Canada, the KLEMS data only cover the business sector. To ensure comparability, for other G7 countries, we exclude public administration, defence, compulsory social security, activities of households as employers, and activities of extraterritorial organizations from output in other G7 countries.

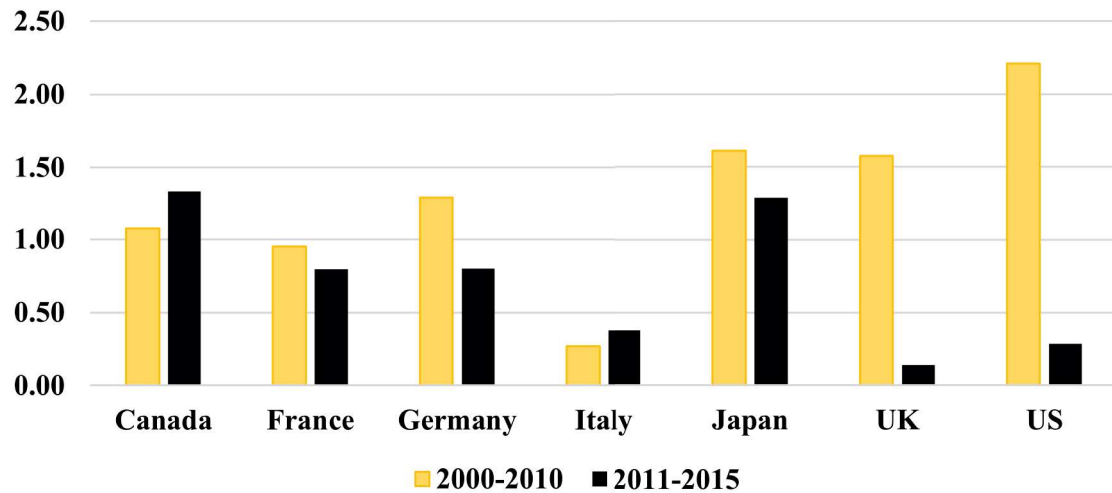
For all countries, we combine industries into 12 major industry groups: agriculture, forestry and fishing; mining and quarrying; manufacturing; utilities; construction; wholesale and retail trade; transportation and storage; accommodation and food services; information and communication; financial, insurance and real estate activities (FIRE); professional, scientific, technical, administrative and support service activities (PSTAS); and community social and personal services. We call the aggregate of those 12 industries “the total business sector”. Real output and inputs for the business sector are aggregated from the industry level using the Törnqvist quantity in-

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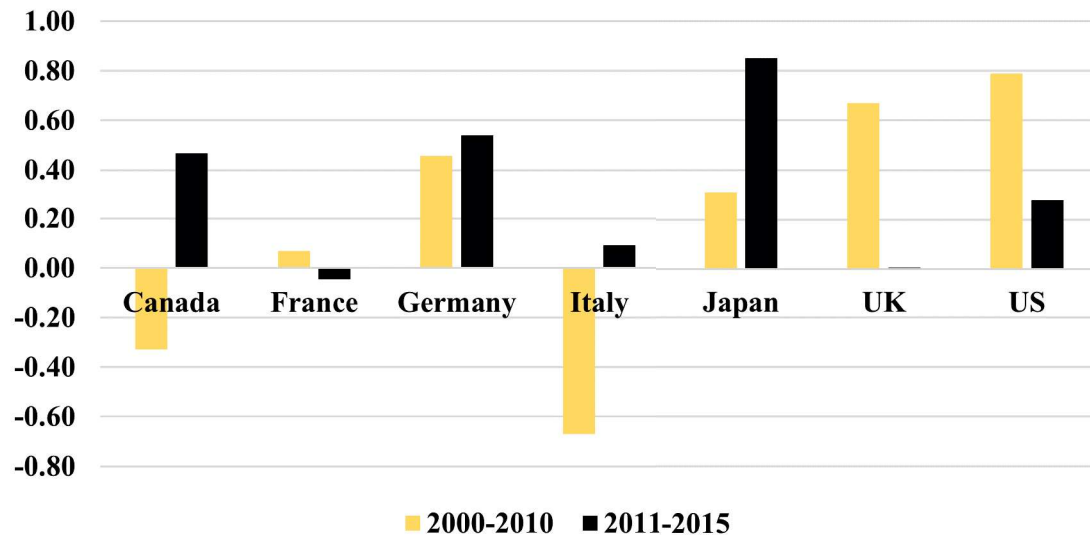
10 The KLEMS database for the United Kingdom has no price data for intermediate inputs as, unlike other national statistical offices which use double deflation to estimate real output at the industry level, the UK statistical office uses a single-deflation approach in its national accounts. As a proxy for the missing data for the United Kingdom, we use the average of intermediate input prices in other G7 countries in Europe (France, Germany and Italy). The proxy is expected to be reasonable as our analysis is only concerned with changes in intermediate input price, not its level.

Chart 2: Business Sector Productivity Growth in G7 Countries, 2000-2010 and 2011-2015 (per cent per year)

Panel A: Labour Productivity



Panel B: Multifactor Productivity



Source: Authors' calculation based on KLEMS data

dex, which is almost the same as the chain-Fisher index.

For all countries, we have data up to 2015. We focus our analysis on 2000-2015, which is divided into two sub-periods 2000-2010 and 2011-2015. The division point was chosen to compare productivity performance among those countries after the global financial crisis. Most of economies started to recover significantly in 2011.

### Empirical Results on Aggregate Productivity Growth in the Business Sector

Before we discuss the empirical results based on KLEMS data, it should be noted that the productivity estimates for the G7 countries in Chart 1 from the OECD are for total economy and also the estimates of labour and capital may be different from KLEMS data in terms of controlling for

**Table 1: Components in the Change of Business Sector Productivity Growth between 2000-2010 and 2011-2015 in G7 Countries (percentage points per year)**

<b>Panel A: Labour Productivity</b>							
	Canada	France	Germany	Italy	Japan	UK	United States
Industry Productivity	0.79	-0.10	-0.48	0.24	0.49	-1.70	-2.13
Price Effect	-0.01	-0.12	0.01	-0.09	-0.57	0.50	-0.02
Size Effect	-0.51	0.05	-0.02	-0.07	-0.30	-0.21	0.15
Interactions	0.00	0.02	-0.01	0.03	0.06	-0.02	0.08
<b>Total</b>	0.26	-0.15	-0.49	0.11	-0.32	-1.43	-1.93
<b>Panel B: Multifactor Productivity</b>							
	Canada	France	Germany	Italy	Japan	UK	United States
Industry Productivity	0.90	0.40	0.81	0.95	1.01	-0.41	-1.07
Price Effect	-0.19	-0.03	0.52	0.57	0.18	0.31	0.28
Size Effect	0.01	-0.52	-1.28	-0.79	-0.65	-0.58	0.14
Interactions	0.07	0.03	0.03	0.04	0.01	0.02	0.15
<b>Total</b>	0.80	-0.12	0.08	0.76	0.55	-0.66	-0.51

Source: Authors' calculation based on KLEMS data.

quality in labour and capital by considering the changes in their compositions. The time periods for the two charts are also different. As a result, the productivity estimates for the total economy from OECD are different from those for the business sector based on KLEMS (Chart 2).

However, the general message from these two productivity series is consistent, that is, Canada improved its productivity growth significantly relative to other G7 countries after the global financial crisis. Labour productivity growth in the Canadian business sector increased from an average of 1.07 per cent per year in 2000-2010 to 1.34 per cent per year in 2011-2015, an increase of 0.26 percentage points per year. The improvement was even larger in MFP from -0.33 per cent per year to 0.47 per cent per year, an increase of 0.80 percentage points.

The improvement in labour and mul-

tifactor productivity in Canada was the largest among the G7 economies. This was followed by Italy which also saw a significant improvement in both labour productivity (0.11 percentage points) and MFP (0.76 percentage points), and Japan in MFP (0.55 percentage points). In contrast, all other G7 countries experienced a decline in labour productivity growth between periods. The largest decline was in the United States. Its labour productivity growth rate declined from 2.21 per cent per year in 2000-2010 to only 0.28 per cent per year in 2011-2015. Similarly, its MFP growth rate also dropped from 0.79 per cent per year to 0.28 per cent per year.

In an on-line appendix to this article,<sup>11</sup> we report and discuss each country's detailed industry contribution to both aggregate labour productivity growth and aggregate MFP growth, which are estimated using the framework developed in the Ap-

<sup>11</sup> The on-line appendix is available at [www.csls/ipm39/Tang\\_Wang\\_Appendix](http://www.csls/ipm39/Tang_Wang_Appendix).

pendix. In the remainder of this section, we focus on the comparison of industry contribution to aggregate labour productivity growth and aggregate MFP growth in Canada relative to the other G7 countries.

### **Country Comparison: Industry Performance and Aggregate Labour Productivity Growth**

Now we compare Canada to other G7 countries and highlight the forces behind Canada's better labour productivity growth after recovering from the global financial crisis. We focus in this subsection on the change in labour productivity growth between the two sub-periods between 2000-2010 and 2011-2015.

Panel A of Table 1 provides a country comparison of the components of the change in labour productivity growth between 2000-2010 and 2011-2015 at the business sector level. It shows that Canada's acceleration in labour productivity growth of 0.26 percentage points after the global financial crisis was the largest among the G7 countries. The superior performance is explained by the large increase in within-industry productivity at 0.79 percentage points, the largest in the G7. Canada also experienced the largest decline in the size effect, but the drop in the size effect only partially offset the increase in the productivity effect. In contrast, the United States had the largest drop in labour productivity growth. This was mainly because the country experienced the largest drop in the labour productivity effect.

Compared with other G7 countries, the positive change in industry contributions to the acceleration in labour productivity

growth in Canada was widespread across industries (Table 2, Panel A). In particular, Canada led in industry contributions from agriculture, forestry and fishing; manufacturing, transportation and storage; and FIRE. Due to the strength of its financial sector and housing market, Canada was the only country experiencing a positive increase in industry contribution from FIRE. Notably, Canada also had the largest drop in the industry contribution from mining and quarrying. This was because the Canadian economy is more resource-based. Oil and other commodity prices substantially dropped starting in 2014.

In contrast, the United States had the largest negative contributions to aggregate labour productivity growth in half of the 12 industries: agriculture, forestry and fishing; manufacturing; wholesale and retail trade; FIRE; PSTAS; and community, social and personal services.

In sum, Canada's greater acceleration in business sector labour productivity growth than other G7 countries was largely due to the slower decline in the size of manufacturing and the strength of FIRE.

### **Country Comparison: Industry Performance and Aggregate MFP Growth**

Canada's acceleration in MFP growth between the two sub-periods was also the largest among G7 countries, followed closely by Italy and Japan. On the other hand, the United States experienced the largest decline in MFP growth during the same periods.

Panel B of Table 1 shows that Canada's superior performance in MFP was mainly due to a significant increase in the produc-

**Table 2: Industry Contribution to the Change in Business Sector Productivity Growth between 2000-2010 and 2011-2015 (Percentage points per year)**

<b>Panel A: Labour Productivity</b>							
	Canada	France	Germany	Italy	Japan	UK	US
Agriculture, forestry and fishing	0.21	0.06	0.00	0.16	0.03	-0.01	-0.06
Mining and quarrying	-1.12	0.00	-0.01	0.03	0.01	-0.32	-0.28
Manufacturing	0.90	0.45	0.01	0.36	-0.15	0.24	-0.08
Utilities	0.07	0.12	-0.18	-0.02	0.00	0.02	-0.11
Construction	-0.05	-0.26	0.14	-0.28	0.41	-0.04	0.06
Wholesale and retail trade	-0.07	-0.06	-0.06	0.22	-0.10	-0.23	-0.13
Transportation and storage	0.18	-0.02	-0.12	0.01	-0.03	0.05	-0.03
Accommodation and food services	0.07	-0.01	0.03	0.01	0.04	0.08	-0.01
Information and communication	-0.06	-0.03	0.05	-0.19	-0.14	-0.04	-0.18
FIRE	0.13	-0.24	-0.32	-0.06	-0.25	-0.30	-0.49
PSTAS	0.01	-0.08	0.02	-0.03	0.00	-0.09	-0.18
Community social and personal services	-0.01	-0.09	-0.06	-0.11	-0.16	-0.79	-0.43
<b>Total Business Sector</b>	0.26	-0.15	-0.49	0.11	-0.32	-1.43	-1.93

<b>Panel B: Multifactor Productivity</b>							
	Canada	France	Germany	Italy	Japan	UK	US
Agriculture, forestry and fishing	0.22	0.06	0.01	0.18	0.05	0.00	-0.05
Mining and quarrying	-1.08	0.00	-0.01	0.04	0.01	-0.31	-0.25
Manufacturing	1.05	0.48	0.14	0.49	0.09	0.34	0.14
Utilities	0.09	0.12	-0.16	0.00	0.04	0.03	-0.08
Construction	-0.03	-0.26	0.17	-0.24	0.48	0.01	0.13
Wholesale and retail trade	0.01	-0.05	0.00	0.31	0.05	-0.13	0.07
Transportation and storage	0.21	-0.02	-0.09	0.05	0.02	0.09	0.02
Accommodation and food services	0.08	-0.01	0.04	0.03	0.07	0.10	0.04
Information and communication	-0.03	-0.03	0.08	-0.15	-0.08	-0.01	-0.08
FIRE	0.21	-0.25	-0.22	0.06	-0.15	-0.15	-0.18
PSTAS	0.05	-0.08	0.09	0.03	0.01	0.00	-0.03
Community social and personal services	0.02	-0.09	0.03	-0.02	-0.05	-0.66	-0.25
<b>Total Business Sector</b>	0.80	-0.12	0.08	0.76	0.55	-0.66	-0.51

Note: FIRE stands for financial, insurance and real estate activities; PSTAS stands for professional, scientific, technical, administrative, and support service activities.  
Source: Authors' calculation based on KLEMS data.

tivity effect. Germany, Italy and Japan also experienced a significant increase in the productivity effect and the price effect, but at the same time, they also sustained a large drop in the size effect. As a result, their accelerations in MFP growth were weaker than that for Canada. France also experienced a significant increase in the productivity effect, but the improvement was more than offset by a drop in the size effect, leading to a small deceleration in MFP growth. The United States had the largest deceleration in MFP growth mainly because it had the largest drop in the productivity effect.

The pattern of industry contributions to the change in MFP growth in Canada relative to other G7 countries over these two sub-periods (Table 2, Panel B) was generally similar to that for labour productivity growth. Again, it shows that the stabilization of manufacturing and the strength of FIRE allowed Canada to be able to overcome the largest drop in industry contribution from mining and quarrying and to enjoy the largest acceleration of MFP growth among G7 countries after 2010.

**Table 3: Average Industry Share of Nominal GDP in Business Sector GDP in G7 Countries, 2000-2010 and 2011-2015 (per cent)**

	Mining and Quarrying		Manufacturing		FIRE	
	2000-2010	2011-2015	2000-2010	2011-2015	2000-2012	2011-2015
Canada	9.5	9.9	19.0	14.2	15.2	15.5
France	0.1	0.1	14.6	12.4	17.7	18.8
Germany	0.2	0.2	23.9	24.3	17.3	16.5
Italy	0.5	0.4	19.0	17.0	18.4	21.1
Japan	0.1	0.1	27.4	26.4	11.2	10.8
UK	2.3	1.8	12.2	10.6	20.9	21.2
United States	2.0	2.9	15.3	14.2	21.8	22.0

Note: FIRE stands for financial, insurance and real estate activities; PSTAS stands for professional, scientific, technical, administrative, and support service activities.  
Source: Authors' calculation based on KLEMS data.

### Industry Perspectives: Mining and Quarrying, Manufacturing, and FIRE

In the world economy, economic activities are highly integrated across countries, especially those associated with mining and quarrying, manufacturing, and FIRE. Those industries also played a dominant role in the change in productivity growth before and after the global financial crisis. Compared to other G7 countries, mining and quarrying was the worst laggard to the revival of productivity growth in Canada while manufacturing was the largest positive contributor and FIRE was the second-largest positive contributor for Canada's higher productivity growth acceleration than other G7 countries except Germany.

The Canadian economy is much more dependant on resources than the other G7 countries. In terms of the share of nominal GDP in the business sector, mining and quarrying was much larger in Canada than in other G7 economies, and the importance increased slightly between the two sub-periods (Table 3).

Both manufacturing and FIRE each play important role in all economies, accounting for between 12 and 25 per cent of nominal business sector GDP. However, except in Germany and Japan, the importance of manufacturing declined in all the economies between 2000-2010 and 2011-2015. The decline was largest in Canada, from 19.0 per cent in 2000-2010 to 14.2 per cent in 2011-2015. The share of FIRE in those economies were fairly stable over the two sub-periods, and the largest positive change was in Italy from 18.4 per cent to 21.1 per cent.

The sharp decline in the manufacturing base in Canada is worrisome as the sector contributes significantly to employment, pays high wages and is the engine of the economy for innovation. Table 4 provides data on the shares of nominal business sector GDP for 10 manufacturing industries in Canada and in the United States in 2000, 2010, and 2015. In total, the manufacturing share of nominal GDP declined by 10 percentage points between 2000 and 2015 in Canada, with all the decline taking place before 2010. The decline took place

<sup>12</sup> For a detailed study of the productivity performance of the coke and refined petroleum industry, see Chan *et al.* (2014).

**Table 4: Manufacturing Industry Share of Business Sector Nominal GDP in Canada and the United States, 2000, 2010, and 2015 (%)**

	Canada			United States		
	2000	2010	2015	2000	2010	2015
Food, beverages and tobacco	2.66	2.49	2.26	1.85	1.81	1.66
Textiles, apparel and leather	0.95	0.24	0.18	0.56	0.21	0.18
Wood, paper and printing	4.06	1.76	1.61	1.51	0.92	0.83
Coke and refined petroleum	0.35	0.68	1.10	0.60	1.03	1.04
Chemicals	1.76	1.37	1.47	2.13	2.61	2.43
Rubber, plastics and non-metallic minerals	1.71	1.22	1.20	1.22	0.78	0.77
Basic and fabricated metal products	3.12	2.01	1.97	1.90	1.33	1.32
Electrical and optical equipment	2.22	1.01	0.74	3.06	2.36	2.16
Machinery and equipment	1.59	1.03	1.10	1.27	0.96	0.99
Transport equipment	5.08	2.03	2.37	2.36	1.62	1.90
Other manufacturing	1.08	0.77	0.67	1.05	0.82	0.72
<b>Total Manufacturing</b>	<b>24.58</b>	<b>14.59</b>	<b>14.66</b>	<b>17.50</b>	<b>14.44</b>	<b>13.99</b>

Source: Authors' calculation based on KLEMS data.

in all industries except coke and refined petroleum.<sup>12</sup> The industry with the largest decline was transport equipment (2.7 percentage points), followed by wood, paper and printing (2.5 percentage points) and electrical and optical equipment (1.5 percentage points). In contrast, the manufacturing share of GDP declined only 3.5 percentage points in total in the United States. Although the decline in the United States was also widespread across industries, the decline in each industry was relatively small, with the largest decline being 0.9 percentage points (electrical and optical equipment).

What were the driving forces of the decline of manufacturing in Canada in 2000-2010? Despite extensive research, the cause for the decline in manufacturing remains a puzzle. Capeluck (2015) provided some potential reasons. However, research suggests non-firm-specific factors might play a role as there was some evidence that the decline was mainly due to the weak performance of large and exporting manufacturing firms (Baldwin *et al.*, 2013; Tang 2014; Tang, 2017). Factors such as the negative im-

pact of the sharp appreciation of Canadian dollar between 2002 and 2008, the weak demand from international markets (especially the U.S. market), and the increase in competition from emerging economies have been suggested to be the driving forces.

In next sub-sections of this section, we provide more evidence by comparing the economic performance of those three industries across G7 countries in terms of economic indicators that are important for productivity growth. We consider growth in real gross output, real gross output price, hours worked, labour productivity and MFP.

### Mining and Quarrying

Compared to other industries, the developments in the mining and quarrying industry were highly volatile, mainly due to the fluctuation in commodity prices. The relative gross output price declined substantially in the second sub-period relative to in the first sub-period in all countries except in Japan after the global financial crisis (Table 5, Panel A). However, the change in other economic indicators were

**Table 5: Output, Hours, Price and Productivity Trends in G7 Countries, 2000-2010 and 2011-2015 (Growth Rate in per cent per year)**

<b>Panel A: Mining and Quarrying</b>										
	Real Gross Output		Hours Worked		Real Gross Output Price		Labour Productivity		MFP	
	2000-2010	2011-2015	2000-2010	2011-2015	2000-2010	2011-2015	2000-2010	2011-2015	2000-2010	2011-2015
Canada	2.35	3.43	6.45	1.04	6.14	-4.12	-3.66	2.90	-3.64	-0.79
France	-2.37	-3.19	-2.73	-2.87	2.51	1.06	1.06	-0.24	-1.29	-1.10
Germany	-2.03	-4.33	-4.97	-4.48	1.69	-0.80	3.02	0.18	1.31	-0.86
Italy	-3.47	6.97	-1.92	-2.55	1.15	-2.17	-1.54	9.72	-2.63	4.70
Japan	-5.30	-2.00	-4.30	4.00	0.70	2.70	0.00	-4.40	-1.30	-2.00
UK	3.00	-6.10	-1.70	2.80	3.30	1.30	5.00	-8.10	3.60	-10.10
United States	1.20	5.33	2.37	3.76	8.71	-6.11	-0.79	1.92	0.88	3.42
<b>Panel B: Manufacturing</b>										
	Real Gross Output		Hours Worked		Real Gross Output Price		Labour Productivity		MFP	
	2000-2010	2011-2015	2000-2010	2011-2015	2000-2010	2011-2015	2000-2010	2011-2015	2000-2010	2011-2015
Canada	-0.27	1.32	-2.18	-0.10	-1.11	0.99	1.87	1.42	0.02	0.51
France	0.04	0.55	-2.21	-0.95	-0.48	-0.08	2.27	1.51	0.48	0.42
Germany	1.94	1.98	-1.14	1.33	0.31	-0.75	3.03	0.62	0.74	0.38
Italy	0.31	-0.65	-1.56	-1.72	-0.15	-0.27	1.82	1.08	-0.06	0.12
Japan	-0.10	0.00	-2.10	-1.00	0.70	0.50	2.30	1.10	0.00	0.00
UK	-0.10	2.00	-4.20	0.40	1.20	0.80	4.30	1.70	1.00	0.50
United States	-0.38	2.40	-3.64	1.54	0.46	-0.96	3.37	0.85	1.00	-0.25
<b>Panel C: FIRE</b>										
	Real Gross Output		Hours Worked		Real Gross Output Price		Labour Productivity		MFP	
	2000-2010	2011-2015	2000-2010	2011-2015	2000-2010	2011-2015	2000-2010	2011-2015	2000-2010	2011-2015
Canada	3.50	3.22	1.98	0.93	-0.39	0.62	0.56	1.70	0.06	1.14
France	2.40	1.17	0.62	0.39	0.19	-0.08	1.79	0.80	0.10	0.16
Germany	1.43	0.53	-0.85	-0.52	0.15	-0.88	2.30	1.07	-0.02	0.11
Italy	1.53	-0.01	0.72	-1.08	1.23	0.29	0.82	1.08	-0.31	0.28
Japan	0.50	1.60	-0.10	-1.30	-0.20	-1.50	0.60	3.10	-1.10	2.10
UK	3.60	2.20	1.00	0.70	1.30	0.60	2.50	1.50	0.50	1.20
United States	2.60	1.77	-0.08	1.43	-0.32	0.64	2.68	0.35	0.56	0.26

Source: Authors' calculation based on KLEMS data.

different across countries. Canada, Italy, and the United States increased real gross output growth and productivity growth in 2011-2015 compared to 2000-2010, but only Japan, the United Kingdom, and the United States managed a significant increase in employment growth. For France and Germany, growth in real gross output, employment or productivity slowed or was negative for most of the economic indicators.

## Manufacturing

In general, manufacturing recovered in 2011-2015 from weakness in 2000-2010. The recovery in output and labour input was more dramatic in Canada, the United Kingdom and the United States and less so in France, Japan and Italy (Table 5, Panel B). Over these two sub-periods, all countries except Canada experienced a slowdown in both labour productivity and MFP growth. Canada also experienced a slowdown in labour productivity growth, but it managed to improve MFP in the second

sub-period compared to a stagnant MFP performance in the previous sub-period.

## **FIRE**

Compared to other countries, the strength of FIRE in Canada stood out across all indicators. Canada led G7 countries in hours worked growth in the 2000 to 2010 period. Despite slower growth after 2010, Canada maintained the highest growth rate in output in both 2000-2010 and 2011-2015 and second best growth rate in hours worked in 2011-2015 (Table 5, Panel C). In addition, Canada enjoyed faster labour productivity and MFP growth in 2011-2015 and had the second largest acceleration for both labour productivity growth and MFP growth, after Japan. The United States was the country with the largest slowdown in both labour productivity and MFP growth.

## **Conclusion**

Canada has emerged as one of the better productivity growth performers among the G7 countries after the global financial crisis, which was in sharp contrast to its relatively weaker productivity growth performance in the 2000s. Canada's better productivity growth performance was due to Canada's improvement in productivity, but more importantly due to the slowdown in productivity growth in other G7 countries, especially in the United States.

Manufacturing played the most important role in Canada's superior productivity performance relative to other G7 countries after the global financial crisis, largely due to the much slower decline of the sector after 2010. Between these two sub-periods, the contribution of manufacturing

to aggregate labour productivity growth increased 0.90 percentage points while in other countries, it ranged from -0.15 percentage points (Japan) to 0.45 percentage (France). Similarly, for MFP, the contribution in Canada increased 1.05 percentage points while in other countries, it ranged from 0.10 percentage points (Japan) to 0.50 percentage points (Italy). The evidence suggests that after a deep restructuring, the Canadian manufacturing sector has settled into a smaller, learner version of itself with an industry mix more aligned with its productive advantages.

Following manufacturing, Canada's relatively better performance in FIRE also contributed significantly to the Canada's productivity growth advantage over other countries. Over these two sub-periods, the contribution of FIRE to aggregate labour productivity growth increased 0.13 percentage points while in other countries, it ranged from -0.06 percentage points (Italy) to -0.49 percentage (the United States). Similarly, for MFP growth, the contribution of FIRE in Canada increased by 0.21 percentage points while in other countries, it ranged from 0.06 percentage points (Italy) to -0.25 percentage points (France). This reflects the strength of Canadian financial, insurance and real estate industries and the further improvement in productivity in this sector after the global financial crisis. This ultimately reflects Canada's sound banking system and better financial regulatory framework.

On the other hand, due to a sharp decline in commodity prices after the global

financial crisis,<sup>13</sup> mining and quarrying made a much larger negative contribution to aggregate productivity growth after the global financial crisis in Canada than in the other G7 countries. Given Canada's reliance on the mining and quarry sector for economic growth, the volatility in the sector will continue to contribute to the change in Canada's productivity growth performance.

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13 See the Bank of Canada commodity price index (BCPI), which is an index of the spot or transaction prices in U.S. dollars of 26 commodities produced in Canada and sold in world markets (<https://www.bankofcanada.ca/rates/price-indexes/bcpi/>).

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## Appendix: Methodology for the Decomposition of Aggregate Productivity Growth

In this Appendix, we develop the methodologies to decompose aggregate labour productivity growth and MFP growth into components at the industry level.

### Decomposing Aggregate Labour Productivity Growth

Let  $V$  and  $V^r$  be nominal and real aggregate value-added,  $P^V$  be aggregate value added implicit price index, and  $L$  be aggregate labour input. The aggregate labour productivity ( $\Omega$ ) is defined as real aggregate value-added per unit of labour, i.e.

$$\Omega^V = V^r/L \quad (1)$$

Define  $V_i$ ,  $Y_i^r$ , and  $P_i^Y$  as nominal value added, real gross output and the gross output price for industry  $i$ , respectively, and also  $M_i^r$ ,  $P_i^M$ , and  $L_i$  as real intermediate inputs, intermediate input price and intermediate input labour, respectively.

With those definitions, the aggregate labour productivity can be traced back to components at the industry level as follows:

$$\begin{aligned} \Omega^V &= \frac{V^r}{L} = \frac{V/P^V}{L} = \frac{\sum_i V_i}{P^V L} \\ &= \frac{\sum_i (P_i^Y Y_i^r - P_i^M M_i^r)}{P^V L} \\ &= \sum_i \left( \frac{P_i^Y Y_i^r L_i}{P^V L_i L} - \frac{P_i^M M_i^r L_i}{P^V L_i L} \right) \\ &= \sum_i l_i (p_i^Y \Omega_i^Y - p_i^M \Omega_i^M) \end{aligned} \quad (2)$$

where  $l_i = L_i/L$ ,  $p_i^Y = P_i^Y/P^V$ ,  $p_i^M = P_i^M/P^V$ ,  $\Omega_i^Y = Y_i^r/L_i$ , and  $\Omega_i^M = M_i^r/L_i$ . They represent the industry labour input share, the relative gross output price, the relative intermediate input price, gross output labour productivity and the intermediate input intensity of industry  $i$ , respectively.

Denote  $\lambda_i^Y = l_i p_i^Y$  and  $\lambda_i^M = l_i p_i^M$ . Define the growth rate between years  $\tau$  and  $t$  for any variable  $X$  as  $\dot{X}_t = (X_t - X_\tau)/X_\tau$ . Based on equation (2), aggregate labour productivity growth over a period (one year or more) from year  $\tau$  to year  $t$  can be written as

$$\begin{aligned} \dot{\Omega}_t^V &= \frac{\Omega_t^V - \Omega_\tau^V}{\Omega_\tau^V} \\ &= \frac{\sum_i [(\lambda_{it}^Y \Omega_{it}^Y - \lambda_{it}^M \Omega_{it}^M) - (\lambda_{i\tau}^Y \Omega_{i\tau}^Y - \lambda_{i\tau}^M \Omega_{i\tau}^M)]}{\Omega_\tau^V} \\ &= \sum_i [\lambda_{i\tau}^Y (\Omega_{it}^Y - \Omega_{i\tau}^Y) - \lambda_{i\tau}^M (\Omega_{it}^M - \Omega_{i\tau}^M)] \\ &\quad + (\lambda_{it}^Y - \lambda_{i\tau}^Y) \Omega_{it}^Y - (\lambda_{it}^M - \lambda_{i\tau}^M) \Omega_{it}^M \\ &= \sum_i [\lambda_{i\tau}^Y (\Omega_{it}^Y / \Omega_\tau^V) \dot{\Omega}_{it}^Y - \lambda_{i\tau}^M (\Omega_{it}^M / \Omega_\tau^V) \dot{\Omega}_{it}^M] \\ &\quad + \sum_i [(\Omega_{i\tau}^Y / \Omega_\tau^V) (1 + \dot{\Omega}_{it}^Y) \Delta \lambda_{it}^Y \\ &\quad - (\Omega_{it}^M / \Omega_\tau^V) (1 + \dot{\Omega}_{it}^M) \Delta \lambda_{it}^M] \end{aligned} \quad (3)$$

It can be derived that

$$\begin{aligned} w_{i\tau}^Y &\cong \lambda_{i\tau}^Y (\Omega_{i\tau}^Y / \Omega_\tau^V) = \frac{L_{i\tau} P_{i\tau}^Y Y_{i\tau}^r / L_{i\tau}}{L_\tau P_\tau^V V_\tau^r / L_\tau} \\ w_{i\tau}^M &\cong \lambda_{i\tau}^M (\Omega_{i\tau}^M / \Omega_\tau^V) = \frac{L_{i\tau} P_{i\tau}^M M_{i\tau}^r / L_{i\tau}}{L_\tau P_\tau^V V_\tau^r / L_\tau} \\ &\quad + \sum_i (\Omega_{i\tau}^Y / \Omega_\tau^V) (1 + \dot{\Omega}_{it}^Y) \Delta \lambda_{it}^Y \\ &= \sum_i w_{i\tau}^Y (1 + \dot{\Omega}_{it}^Y) (\dot{p}_{it}^Y + \dot{l}_{it} + \dot{p}_{it}^Y \dot{l}_{it}) \\ &\quad + \sum_i (\Omega_{i\tau}^M / \Omega_\tau^V) (1 + \dot{\Omega}_{it}^M) \Delta \lambda_{it}^M \\ &= \sum_i w_{i\tau}^M (1 + \dot{\Omega}_{it}^M) (\dot{p}_{it}^M + \dot{l}_{it} + \dot{p}_{it}^M \dot{l}_{it}) \end{aligned} \quad (4)$$

So we have

$$\begin{aligned}
\dot{\Omega}_t^V &= \sum_i w_{i\tau}^Y [\dot{\Omega}_{it}^Y + (1 + \dot{\Omega}_{it}^Y) \\
&\quad (\dot{p}_{it}^Y + \dot{l}_{it} + \dot{p}_{it}^Y \dot{l}_{it})] \\
- \sum_i w_{i\tau}^M [\dot{\Omega}_{it}^M + (1 + \dot{\Omega}_{it}^M) (\dot{p}_{it}^M + \dot{l}_{it} + \dot{p}_{it}^M \dot{l}_{it})] \\
&= \sum_i w_{i\tau}^Y [\dot{\Omega}_{it}^Y + \dot{p}_{it}^Y + \dot{l}_{it} + \dot{p}_{it}^Y \dot{l}_{it} + \dot{\Omega}_{it}^Y \\
&\quad (\dot{p}_{it}^Y + \dot{l}_{it} + \dot{p}_{it}^Y \dot{l}_{it})] \\
- \sum_i w_{i\tau}^M [\dot{\Omega}_{it}^M + \dot{p}_{it}^M + \dot{l}_{it} + \dot{p}_{it}^M \dot{l}_{it} + \dot{\Omega}_{it}^M \\
&\quad (\dot{p}_{it}^M + \dot{l}_{it} + \dot{p}_{it}^M \dot{l}_{it})] \\
&= \sum_i (w_{i\tau}^Y \dot{\Omega}_{it}^Y - w_{i\tau}^M \dot{\Omega}_{it}^M) \\
&\quad + \sum_i (w_{i\tau}^Y \dot{p}_{it}^Y - w_{i\tau}^M \dot{p}_{it}^M) \\
&\quad + \sum_i (w_{i\tau}^Y - w_{i\tau}^M) \dot{l}_{it} \\
&\quad + \sum_i \{w_{i\tau}^Y [\dot{p}_{it}^Y \dot{l}_{it} + \dot{\Omega}_{it}^Y (\dot{p}_{it}^Y + \dot{l}_{it} + \dot{p}_{it}^Y \dot{l}_{it})] \\
&\quad - w_{i\tau}^M [\dot{p}_{it}^M \dot{l}_{it} + \dot{\Omega}_{it}^M (\dot{p}_{it}^M + \dot{l}_{it} + \dot{p}_{it}^M \dot{l}_{it})]\} \\
&\quad (5)
\end{aligned}$$

## Decomposing Aggregate MFP Growth

Let  $I$  be aggregate input.<sup>14</sup> Aggregate MFP is defined as real value added per unit of aggregate input:

$$X = V^r / I \quad (6)$$

Denote  $P^I$  as the aggregate input price and as total input and its price for in-

dustry  $i$ . With these definitions, the aggregate MFP can be traced back to components at the industry level as follows:

$$\begin{aligned}
X &= \frac{V^r}{I} = \frac{V}{P^V I} = \frac{\sum_i (Y_i - M_i)}{P^V I} \\
&= \frac{\sum_i (P_i^Y y_i^r - P_i^M M_i^r)}{P^V I} \\
&= \sum_i \left( \frac{P_i^Y / P_i^I}{P^V / P^I} \frac{Y_i^r}{I_i} \frac{P_i^I I_i}{P^I I} - \frac{P_i^M / P_i^I}{P^V / P^I} \frac{M_i^r}{I_i} \frac{P_i^I I_i}{P^I I} \right) \\
&= \sum_i \Theta_i (\omega_i^Y X_i^Y - \omega_i^M X_i^M) \quad (7)
\end{aligned}$$

where  $X_i^Y \cong Y_i^r / I_i$ ,  $X_i^M \cong M_i^r / I_i$ ,  $\Theta_i \cong \frac{P_i^I I_i}{P^I I}$ ,  $\omega_i^Y \cong \frac{P_i^Y / P_i^I}{P^V / P^I}$ , and  $\omega_i^M \cong \frac{P_i^M / P_i^I}{P^V / P^I}$ .

They represents real output per unit of total input (or MFP), intermediate input intensity (in all inputs), the ratio of industry total input cost to aggregate total input cost, the ratio of industry relative output price ( $P_i^Y / P^V$ ) to the industry real total input price ( $P_i^I / P^I$ ), and the ratio of the industry real intermediate input price ( $P_i^M / P^V$ ) to the industry real total input price.<sup>15</sup>

14 The aggregate input index can be measured as a Törnqvist index,  $\Delta \ln(I_t) = \sum_j \bar{w}_{jt} \Delta \ln(I_{jt})$ , of labour, capital and intermediate inputs, with  $\bar{w}_{jt}$  being the two-period average cost share of the corresponding input. For the aggregate input, the aggregate input index is then indexed to the total input costs in the base year.

15 We call  $P_i^Y / P^V$  industry real input price,  $P_i^I / P^I$  industry input price, and  $P_i^M / P^V$  industry real intermediate price as the industry prices are deflated by aggregate prices.

Define  $s_i^Y = \Theta_i \bar{\omega}_i^Y$  and  $s_i^M = \Theta_i \bar{\omega}_i^M$ . The aggregate MFP growth over a period from year  $\tau$  to year  $t$  (one year or more) can be written as

$$\begin{aligned}
X_t^{\&} &= \frac{X_t - T_\tau}{X_\tau} \\
&= \frac{\sum_i [(s_{it}^Y X_{it}^Y - s_{it}^M X_{it}^M) - (s_{i\tau}^Y X_{i\tau}^Y - s_{i\tau}^M X_{i\tau}^M)]}{X_\tau} \\
&= \frac{\sum_i [s_{i\tau}^Y (X_{it}^Y - X_{i\tau}^Y) - s_{i\tau}^M (X_{it}^M - X_{i\tau}^M)] + (s_{it}^Y - s_{i\tau}^Y) X_{it}^Y - ((s_{it}^M - s_{i\tau}^M) X_{it}^M)}{X_\tau} \\
&= \sum_i [s_{i\tau}^Y (X_{i\tau}^Y / X_\tau) \dot{X}_{it}^Y - s_{i\tau}^M (X_{i\tau}^M / X_\tau) \dot{X}_{it}^M] \\
&\quad + \sum_i [(X_{i\tau}^Y / X_\tau) (1 + \dot{X}_{it}^Y) \Delta s_{it}^Y \\
&\quad - (X_{i\tau}^M / X_\tau) (1 + \dot{X}_{it}^M) \Delta s_{it}^M] \quad (8)
\end{aligned}$$

It can be derived that

$$\begin{aligned}
w_{i\tau}^Y &\cong s_{i\tau}^Y (X_{i\tau}^Y / X_\tau) = \frac{P_{i\tau}^Y Y_{i\tau}^r}{P_\tau^Y V_\tau^r}, \\
w_{i\tau}^M &\cong s_{i\tau}^M (X_{i\tau}^M / X_\tau) = \frac{P_{i\tau}^M M_{i\tau}^r}{P_\tau^M V_\tau^r}, \\
&\quad \sum_i (X_{i\tau}^Y / X_\tau) (1 + \dot{X}_{it}^Y) \Delta s_{it}^Y \\
&= \sum_i w_{i\tau}^Y (1 + \dot{X}_{it}^Y) (\dot{\omega}_{it}^Y + \dot{\Theta}_{it} + \dot{\omega}_{it}^Y \dot{\Theta}_{it}), \\
&\quad \sum_i (X_{i\tau}^M / X_\tau) (1 + \dot{X}_{it}^M) \Delta s_{it}^M \\
&= \sum_i w_{i\tau}^M (1 + \dot{X}_{it}^M) (\dot{\omega}_{it}^M + \dot{\Theta}_{it} + \dot{\omega}_{it}^M \dot{\Theta}_{it}) \quad (9)
\end{aligned}$$

Thus, equation (8) becomes

$$\begin{aligned}
\dot{X}_t &= \sum_i w_{i\tau}^Y [\dot{X}_{it}^Y + (1 + \dot{X}_{it}^Y) \\
&\quad (\dot{\omega}_{it}^Y + \dot{\Theta}_{it} + \dot{\omega}_{it}^Y \dot{\Theta}_{it})] \\
&\quad - \sum_i w_{i\tau}^M [\dot{X}_{it}^M + (1 + \dot{X}_{it}^M) \\
&\quad (\dot{\omega}_{it}^M + \dot{\Theta}_{it} + \dot{\omega}_{it}^M \dot{\Theta}_{it})] \\
&= \sum_i w_{i\tau}^Y [\dot{X}_{it}^Y + \dot{\omega}_{it}^Y + \dot{\Theta}_{it} + \dot{\omega}_{it}^Y \dot{\Theta}_{it} \\
&\quad + \dot{X}_{it}^Y (\dot{\omega}_{it}^Y + \dot{\Theta}_{it} + \dot{\omega}_{it}^Y \dot{\Theta}_{it})] \\
&\quad - \sum_i w_{i\tau}^M [\dot{X}_{it}^M + \dot{\omega}_{it}^M + \dot{\Theta}_{it} + \dot{\omega}_{it}^M \dot{\Theta}_{it} \\
&\quad + \dot{X}_{it}^M (\dot{\omega}_{it}^M + \dot{\Theta}_{it} + \dot{\omega}_{it}^M \dot{\Theta}_{it})] \\
&= \sum_i (w_{i\tau}^Y \dot{X}_{it}^Y - w_{i\tau}^M \dot{X}_{it}^M) \\
&\quad + (w_{i\tau}^Y \dot{\omega}_{it}^Y - w_{i\tau}^M \dot{\omega}_{it}^M) \\
&\quad + \sum_i (w_{i\tau}^Y - w_{i\tau}^M) \dot{\Theta}_{it} \\
&\quad + \sum_i \{w_{i\tau}^Y [\dot{\omega}_{it}^Y \dot{\Theta}_{it} + \dot{X}_{it}^Y (\dot{\omega}_{it}^Y + \dot{\Theta}_{it} + \\
&\quad \dot{\omega}_{it}^Y \dot{\Theta}_{it})] - w_{i\tau}^M [\dot{\omega}_{it}^M \dot{\Theta}_{it} \\
&\quad + \dot{X}_{it}^M (\dot{\omega}_{it}^M + \dot{\Theta}_{it} + \dot{\omega}_{it}^M \dot{\Theta}_{it})]\} \quad (10)
\end{aligned}$$

# A Vertically Integrated Perspective on Nordic Manufacturing Productivity

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## ABSTRACT

Specialization, at the national and global level, and a growing importance of knowledge-based capital in current growth processes have led to a renewed interest in a vertically integrated perspective on productivity. This means that the focus is on all steps of the production process, regardless of in what sector or country the value creation takes place. From this perspective, Norway has improved its relative productivity since 2000 and is now the leader among the Nordic countries. Finland – and Sweden to some extent – have performed relatively poorly. Using import multipliers and splitting the domestic production chain into two productivity measures, this article shows that the vertically integrated perspective can contribute to new insights about productivity developments in trade-dependent and highly specialized countries. Important aspects of a policy for an enhanced vertically-integrated productivity are the quality of human capital, enhanced diffusion of knowledge and innovations and a holistic view of economic growth.

According to economic theory, labour productivity is determined by human capital, capital stock, intermediate inputs and a residual: multifactor productivity.<sup>2</sup> Based on theory, empirical research on productivity usually focuses on analyses of individual countries and sectors.<sup>3</sup> Accord-

ingly, there is less emphasis on how the necessary trade in intermediate inputs – within and between countries – affects productivity. This exclusive focus of productivity analysis on the final stage of the production process does not capture the implications for productivity from changes in the

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2 Multifactor productivity (MFP) reflects the total efficiency at which the production factors are combined in the production process. MFP growth is often interpreted as a measure of technical change, but this is not entirely correct since new technologies can also be channelled through the capital stock and the intermediate inputs. See OECD (2001).

3 Carvalho (2014), Timmer (2017), Gu and Yan (2017) and Timmer and Ye (2018, 2020). See also Acemoglu and Azar (2020).

4 Timmer and Ye (2020:425) argue in the following way about productivity research: "... the canonical KLEMS framework is versatile and when appropriately modified, can also be applied outside the traditional confines of analyses of economic growth in individual countries and industries..."

organization of production.<sup>4</sup>

However, in recent years, there has been a renewed academic and policy interest in a vertically integrated production and productivity perspective.<sup>5</sup> This means that the focus is on the entire production process, irrespective of in what country or sector the value creation takes place. Therefore, the limelight is on how trade in intermediate inputs creates and diffuses productivity by linking different stages of the production process, which finally end up as a final product.

Taking the fact that this perspective is particularly relevant for the most technologically advanced, highly specialized and trade-dependent countries as the starting point, this article aims at empirically analyzing the vertically integrated productivity of the manufacturing sector in the Nordic countries for the first time.<sup>6</sup> The article addresses the following questions: (1) How has the productivity of the manufacturing sector developed, in absolute and relative terms, since the turn of the millennium? (2) How has the productivity of the manufacturing sub-sectors developed, in absolute and relative terms, since the turn of the millennium? (3) What role does the use of imported intermediate inputs play for vertically integrated productivity?

To put these three questions into some perspective, a fourth question is: (4) how and to what extent does this vertically integrated perspective give new or nuanced

productivity insights? This is explored by splitting the domestic production process into two productivity measures: the conventional, sectoral-based labour productivity and the labour productivity along the domestic supply chains. The period studied is 2000-14.

The article is structured as follows. The next section clarifies the theoretical and empirical framework. Then follows an empirical section, sub-divided into separate but related topics. In a concluding section, the empirical results are synthesized and some policy perspectives are presented.

## Theoretical and Empirical Framework

### Renewed Interest in a Vertically Integrated Productivity Perspective

One reason behind the renewed interest in a vertically integrated productivity perspective is the ICT-driven, intensified interaction between different parts of the economy, in particular between the manufacturing sector and the service sector. This means that the network of intermediate input flows has become denser and often more complicated (Acemoglu and Azar, 2020). This integration, driven by specialization and a larger presence of services in the production and delivery of manufacturing products, has become increasingly high-skilled.

One explanation for this is that the knowledge-based (or intangible) capital –

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<sup>5</sup> From a production perspective, see, for example, OECD (2013a), Timmer *et al.* (2013), Timmer *et al.* (2014), Statistics Denmark (2017), OECD (2017), ECB (2019), IMF (2019), WTO (2019), Ponte *et al.* (2019) and World Bank (2020). See also Baldwin (2016, 2017, 2019).

<sup>6</sup> The Nordic countries are defined as Sweden, Norway, Finland, and Denmark.

such as data, skill development, management and governance, trademark and research and development (R&D) – has become increasingly important for the productivity of manufacturing production (Jona-Lasinio and Meliciani, 2019).<sup>7</sup> In the wake of this, we have seen a strong growth in the sector for knowledge-intensive business services and it contributes to the value creation of manufacturing production to an increasing extent, not the least in the Nordic countries (Criscuolo and Timmis, 2018a). As a consequence, manufacturing production in the Nordic countries has become more specialized in those production activities that are related to high-skilled labour (Timmer *et al.*, 2014).

A second explanation for the renewed interest is that, not the least in the wake of the financial crisis in 2008 and the catastrophe in Fukushima in 2011, there is an enhanced focus on how productivity shocks at the micro level, through the intermediate input structure, can affect macroeconomic performance (Carvalho and Tahbaz-Salehi, 2019). This means that, as a consequence of their central role as subcontractors in the production system, a few sectors can be decisive for the aggregate development (Acemoglu *et al.*, 2016). The research on how inefficiencies at the micro level, through the intermediate input structure, affect the effi-

ciency at the macro level is closely related to this, and can contribute to the understanding of the large differences in material welfare between countries (Jones, 2013; Restuccia and Rogerson, 2017).

A third explanation concerns the emergence of global value chains and how the global trade in intermediate inputs affects the productivity of the firms involved (Timmer and Ye, 2020).<sup>8</sup> This means that a manufacturing product today contains a considerably larger share of imported intermediates than before. Apart from weakening the link between global trade and domestic growth, a consequence of these chains is that the difference in productivity between the globally oriented and the most productive firms, and the domestically-oriented firms seems to have widened. Based on this productivity gap, OECD (2015) concludes that the diffusion of productivity within countries cannot be taken for granted and that the political system should therefore implement policies to improve the national diffusion process.

Manufacturing production is particularly relevant in this context, since it is highly specialized and thus buys considerable amounts of intermediate inputs from other sectors and countries. With a more efficient diffusion process, the gains from an improved productivity will also be more

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<sup>7</sup> A significant part of knowledge-based capital is classified as current consumption in the national accounts (Corrado *et al.* 2009; OECD 2013b; Corrado *et al.*, 2020). This means that this type of capital is often diffused in the economy through the intermediate input structure, not through the capital stock. With a growing use of knowledge-based capital, trade in intermediate inputs has thus become a more important channel for the productivity development. Based on the argument that standard macroeconomic and growth models often ignore the role of intermediate inputs, Jones (2013) argues that in the long run, there is no difference between capital and intermediate inputs: both are produced factors of production. Therefore, intermediate inputs can be seen as another form of capital. When Corrado *et al.* (2020:364) treat these two types of capital as one, they use the wording: “This broad view of investment. . .”.

<sup>8</sup> See also the overview in Criscuolo and Timmis (2017) and the results in Criscuolo and Timmis (2018b) and Gal and Witheridge (2019).

evenly spread among the working population (OECD, 2016).

### **Earlier Research on Vertically Integrated Productivity**

Behind the renewed interest in a vertically integrated productivity perspective, there are some research traditions that have more explicitly been interested in the interaction between sectors and the importance of the intermediate input structure in the post war period. Without any claim to being a complete overview, Leontief (1936, 1941) and the input-output theory (IO) which is established therein constitute an empirical starting point for much of this research. The focus of this theory is on the interdependencies between sectors that are created by the trade in intermediate inputs, and from a (labour-) productivity perspective, the central question is how much labour that is required to finalize a product, regardless of where in the economy the employment is generated.<sup>9</sup>

Another research tradition takes its starting point in an evolutionary perspective on how technical change and innovations are created and diffused in the economy.<sup>10</sup> A central objective in this research is to open the black box and in more detail understand what drives productivity. The interaction within and between firms and

sectors is central here – how production is organized and how the interaction works between the micro and macro level of the economy.

### **Pasinetti's Theory on Economic Growth and Dynamics**

A third research area which more explicitly considers productivity from a vertically integrated perspective belongs to the post-Keynesian tradition. With the ambition to reconnect to the classical economists, such as Adam Smith and his reasoning on what production steps are required to produce a woolen coat, Sraffa (1960) established the concept of a sub-system.<sup>11</sup> This involves a vertical intersection of the economy – a production process from the very beginning to the very end, where labour used in earlier production stages is embedded in the final product. Taking the classical economists as well as Leontief and Sraffa as his starting point, Pasinetti (1973, 1981, 1993) develops a growth theory based on the premises that economic theory should take a larger and more detailed interest in technical change, technology diffusion and structural change.<sup>12</sup>

The core of Pasinetti's theory lies in the production process, with division of labour and specialization. Following the classical political economists, the theory seeks to an-

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<sup>9</sup> Carter (1970) constitutes an early and important contribution to productivity research from an IO perspective.

<sup>10</sup> See Nelson and Winter (1982) and Rosenberg (1982). In a Nordic context, related discussions are found in Dahmén (1950, 1988), Lundvall (2001) and Fagerberg (2002).

<sup>11</sup> Brondino (2019) uses sub-systems in order to analyze the productivity development of the Chinese economy in the period 1995-2009.

<sup>12</sup> With a focus on technical change and its effect on the dynamic course of the economy, Pasinetti also finds inspiration from the evolutionary theory, in particular Schumpeter. See the contributions in Arena and Porta (2012) for a discussion of Pasinetti's theory. See also Garbellini and Wirkierman (2014).

answer the question of how a “pure” labour economy – where production is carried out with labour as the only primary factor of production – and its productivity are developed over time as a consequence of individual and collective learning.<sup>13</sup> This learning contributes to the technical change, which in turn affects how much and what kind of intermediate inputs that are required to finalize a product.<sup>14</sup> Hence, the dynamics and the structural change in the economy are captured by how the need for labour per produced product changes over time – through labour productivity. With the purpose of operationalizing these dynamics, Pasinetti establishes the concept of vertically integrated sectors and the total labour coefficient (TLC). The former refers to the different vertical cross section parts of the economy, and the latter to the total amount of labour needed in the domestic economy to make a product.

### Leontief’s Inverse and Pasinetti’s Total Labour Coefficients

Taking interdependent sectors as the starting point, the IO-analysis takes off from the classical political economy. Based on this, Leontief developed a production theory which aims at carefully studying how production processes are organized and how they affect the functioning of the economy.<sup>15</sup> Leontief (1991) compared his approach to opening the hood in order to

obtain an in-depth understanding of how the economic engine works. The main tool for this improved understanding is equation (1), in which the relation between final demand, ( $f$ ), and gross output, ( $x$ ), is clarified:

$$x = (I - A)^{-1}f = Lf \quad (1)$$

where  $(I - A)^{-1} = L = [l_{ij}]$  is the Leontief inverse – the core of the IO-analysis.  $l_{ij}$  is a partial derivative and expresses the total effect on production in sector  $i$  of a one unit change in final demand in sector  $j$  ( $l_{ij} = (\delta x_i)/(\delta f_j)$ ), including all subsequent rounds of indirect demand for intermediate inputs.

The learning that affects the use of technology in Pasinetti’s theory changes the partial derivatives in the Leontief inverse – how much and what kind of intermediate inputs that are required in different sectors in order to finalize a product. However, Pasinetti argues that Leontief’s view of the trade in intermediate inputs should be supplemented in order to better understand the dynamics of the economy. The reason for this extension is that changes in individual coefficients in the Leontief inverse make it difficult to compare the whole production system over time, since there are continuous changes in its underlying structure. Therefore, the focus should not pri-

13 In recent models focusing on productivity from a vertically integrated perspective, the starting point is often also a “pure” labour economy, where the primary production factor labour and intermediate inputs are transformed into final products. See, for example, Acemoglu *et al.* (2016).

14 This learning is related to what is defined by Lundvall (2001) as the learning economy: how networks of and cooperation between suppliers, customers and competitors can contribute to learning and innovation, how these networks contribute to the diffusion process, and therefore improve productivity growth.

15 See Miller and Blair (2009) for a review of IO theory and its applications.

marily be on individual cells in the Leontief inverse, but on each sector's column sum. These are economically relevant even if the technical change alters the size of individual coefficients and their mutual relationships in Leontief's inverse. Consequently, Pasinetti considers Leontief's IO-analysis and his growth theory as complements, where the latter has a dynamic focus and the former focuses more on detailed analyses of the functioning of the economy in a given period.

In order to calculate Pasinetti's total labour coefficients, the Leontief inverse is pre-multiplied by a matrix, consisting of the direct labour coefficient (DLC) of each sector in the economy, expressed as the inverse of the gross output per person employed, on the main diagonal, and zeros elsewhere. The result is the matrix – total labour coefficients (TLC). The column sum of sector  $i$  in period  $t$  in this matrix expresses the amount of employment that is required in all production stages within the domestic economy in order to finalize a unit of production in sector  $i$ :

$$TLC = DLC(I - A)^{-1} \quad (2)$$

The sum of the columns constitutes the

labour productivity measure used in this article.<sup>16</sup> The change in the TLC coefficient for sector  $i$  therefore captures the "net effect" of the changes in labour use in those sectors that are part of the vertically integrated production process of sector  $i$  – in all of the upstream activities that are required to finalize the product.

The statistics used in this article are from the World Input-output Database (WIOD) and are expressed in constant prices ( $t - 1$ ).<sup>17</sup> The conversion into a common currency (dollar) is made using market exchange rates.<sup>18</sup> Employment is defined as the number of people engaged. The IO tables follow ISIC Rev 4 and SNA 2008.<sup>19</sup>

## Empirical Analysis

### Vertically Integrated Productivity in Nordic Manufacturing Sub-sectors

As stated earlier, the main approach of productivity research has for a long time been to focus on individual sectors and countries.<sup>20</sup> Apart from the arguments already put forward, there are good reasons for research to empirically explore the theoretical insights of Domar (1961) and Hultén (1978), that productivity in individual sectors affects other parts of the economy through the intermediate input struc-

16 Multifactor productivity can also be used when applying a vertically integrated perspective. See, for example, Gu and Yan (2017) and Timmer (2017).

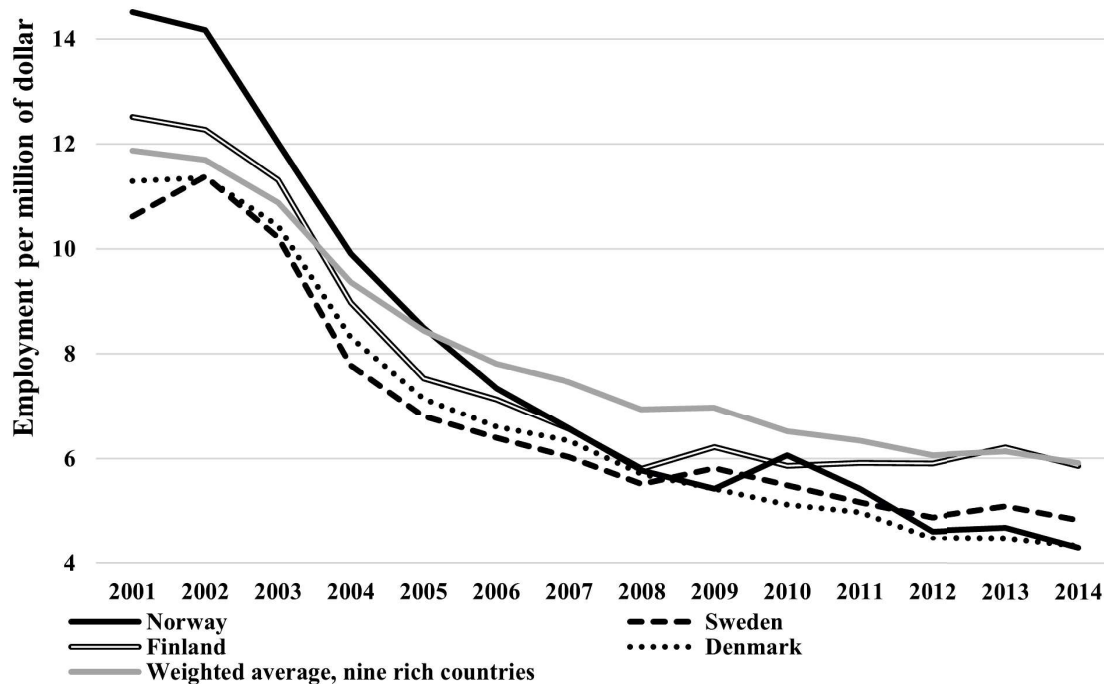
17 See Dietzenbacher *et al.* (2013) and Timmer *et al.* (2016) for a description of the database.

18 Samuels and Strassner (2019) discuss how WIOD and similar, globally oriented, databases should be improved. Not the least, it is argued, this would enhance the understanding of where productivity is generated in the world economy, and how it is diffused through the global trade in intermediate inputs.

19 In this article, the manufacturing sector is defined as SNA 10-33.

20 Gu and Yan (2017:113) argue in the following way about the traditional growth accounting framework and standard measures of productivity: "... fail to capture the impact that productivity gains in upstream industries have on productivity gains in downstream industries."

Chart 1: Labour Productivity Levels in the Nordic Countries and the Western World, Expressed as TLC Coefficients, 2001-14.



Note: Total Labour Coefficient (TLC) is defined as the number of employed that are needed in the domestic economy in order to produce a manufacturing product at the value of one million (constant dollars). Source: WIOD and author's calculations

ture.<sup>21</sup>

How has Nordic manufacturing production developed from a vertically integrated productivity perspective since the turn of the millennium? Based on equation 2, the TLC coefficients was calculated for the manufacturing sector for the Nordic countries and an average of nine rich Western countries.<sup>22</sup> This means that Chart 1 answers the question: how much labour is

needed in the domestic economy in order to finalize the production of a manufacturing product at a value of one million dollar? As appears from the chart, the distribution in 2001 was between 10.6 workers in Sweden and 14.5 workers in Norway – with Denmark (11.3) and Finland (12.5) in between. In relation to Sweden, this means that at the turn of the millennium, about 35 per cent more labour was required along the

21 Domar (1961) operationalizes this insight by weighting sectors into larger aggregates with weights that sum to more than one (Domar's weights). Hultén (1978) formalized this line of thought. See Baqaee and Farhi (2020) for a recent analysis of Domar's and Hultén's theory with less restrictive assumptions. Apart from the references previously mentioned, see also the following examples of productivity research with the starting point in a vertically integrated perspective: Wolff (1994, 2011), De Juan and Febrero (2000), Dietzenbacher *et al.* (2000), Ten Raa and Wolff (2000, 2001, 2012), Garbellini and Wirkierman (2009), Garbellini (2014) and Lind (2014).

22 Timmer (2017) and Timmer and Ye (2018, 2020) are examples of recent research using TLC coefficients. The nine rich countries are the United States, Germany, Great Britain, France, the Netherlands, Belgium, Denmark, Finland and Norway. Final demand has been used as weights when creating the averages for the aggregate manufacturing sector.

manufacturing production chains in Norway in order to produce a manufacturing product.

At an overall level, Chart 1 illustrates the favourable productivity growth that characterized the Western world in the years after the turn of the millennium – in this case expressed as a large reduction in the need for labour per manufacturing product – but that the growth rate was weakened already in the years before the financial crisis. Between 2001 and 2008, the need for labour per manufacturing product decreased by an average of 12.3 per cent per year in Norway and by 8.9 per cent in Sweden.<sup>23</sup> With an annual productivity growth somewhat above 9 per cent in Denmark, and 10 per cent in Finland, this means that Sweden showed the least favourable growth among the Nordic countries in these years, although being ahead of the average of the nine rich countries (-7.4 per cent). After the financial crisis, we see a continued synchronized weakening of the productivity growth in the domestic manufacturing production processes in the Nordic countries. However, Norway is still at the top with a reduced need for labour of about 4.5 per cent per year in the years 2009-14 (Denmark -4.4 per cent). Sweden falls back to 3.7 per cent, but the weak growth in Finland is particularly remarkable – with an average productivity growth of only 1.2 per cent per year after the financial crisis.

Altogether, the pattern between 2001 and 2014 means that the need for labour

per manufacturing product decreased by 70 per cent in Norway, by slightly more than 60 per cent in Denmark and by slightly more than 50 per cent in Sweden and Finland. Besides the fact that this shows how dependent the manufacturing sector is on a growing (global) demand for maintaining its role as an employment generator, this gives a good indication of the competitiveness of the Norwegian manufacturing sector, in terms of its vertically integrated productivity, having shown a strong development in a Nordic perspective since the turn of the millennium. This has also been reinforced after the financial crisis. Finland's productivity advantage of slightly more than 10 per cent versus Norway at the turn of the millennium has been transformed to a productivity lag of more than 30 per cent.

### **Vertically Integrated Productivity in Nordic Manufacturing**

What can we learn from the disaggregated developments underlying the manufacturing sector as a whole? Is the strong Norwegian performance concentrated in a few sub-sectors, or is it broad based and stems from major parts of the manufacturing sector? The World Input-Output Database (WIOD) contains 19 manufacturing sub-sectors. Panel A of Table 1 summarizes the yearly compound growth rates of the total labour coefficient of these 19 sub-sectors for the four Nordic countries – and an unweighted average of these countries (Nordics) – between 2001 and 2014 ( $\Delta$

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<sup>23</sup> As will be clear later on in the article, these extraordinary high growth rates are partly due to an substantial increase in the use of imported intermediate inputs.

**Table 1: Total Labour Coefficient in Manufacturing Industries in Nordic Countries**

<b>Panel A: Yearly Compound Productivity Growth Rate between 2001 and 2014 (<math>\Delta</math> (%))</b>					
	Denmark	Finland	Norway	Sweden	Nordics
Food, beverage, tobacco	-7.4	-6.0	-8.4	-6.2	-7.0
Textile, clothing, leather	-7.0	-6.1	-7.7	-5.4	-6.5
Wood and cork	-5.4	-5.0	-5.1	-5.1	-5.2
Paper and pulp	-6.2	-4.3	-4.8	-4.4	-4.9
Printing and recorded media	-5.2	-3.8	-6.7	-4.8	-5.1
Coke and petroleum	-7.5	-8.7	-9.8	-5	-7.8
Chemicals	-7.9	-5.5	-10.1	-6.0	-7.4
Pharmaceuticals	-6.0	-8.6	-11.8	-5.4	-8.0
Rubber and plastics	-6.4	-5.7	-7.6	-5.2	-6.2
Other non-metallic	-6.6	-5.5	-8.4	-6.5	-6.7
Basic metals	-6.7	-5.7	-6.5	-6.1	-6.2
Metals, except machinery	-5.6	-5.2	-7.1	-5.9	-5.9
Computer and electronics	-5.6	-4.5	-6.6	-7.6	-6.1
Electrical equipment	-6.7	-6.2	-7.7	-5.7	-6.6
Machinery and equipment	-7.2	-6.5	-8.9	-5.9	-7.1
Motor vehicles	-7.0	-6.3	-7.6	-5.9	-6.7
Other transport (e.g ships)	-4.6	-6.4	-8.1	-5.6	-6.2
Furniture	-6.4	-4.5	-6.9	-5.2	-5.8
Repair of machinery	-7.1	-5.4	-6.9	-4.7	-6.0
<b>Panel B: Labour Productivity Level in 2014</b>					
	Denmark	Finland	Norway	Sweden	Nordics
Food, beverage, tobacco	5.1	9.8	5.4	7.0	6.8
Textile, clothing, leather	4.1	9.2	5.8	6.8	6.5
Wood and cork	6.6	7.6	6.5	6.9	6.9
Paper and pulp	5.1	5.2	5.1	5.0	5.1
Printing and recorded media	7.1	9.1	5.4	7.7	7.3
Coke and petroleum	1.0	1.5	2.2	1.4	1.5
Chemicals	2.8	4.0	2.4	3	3.1
Pharmaceuticals	3.3	3.2	2.2	3.3	3.0
Rubber and plastics	4.7	6.2	4.3	5.8	5.2
Other non-metallic	5.3	6.8	4.1	5.6	5.5
Basic metals	4.2	3.9	2.8	4.2	3.8
Metals, except machinery	6.3	7.9	5	6.4	6.4
Computer and electronics	4.0	4.4	3.9	3.0	3.8
Electrical equipment	4.5	5.1	4.1	5.2	4.7
Machinery and equipment	4.2	5.2	3.6	5.2	4.6
Motor vehicles	4.0	5.5	3.7	4.4	4.4
Other transport (e.g ships)	5.8	6.2	3.9	4.7	5.1
Furniture	5.3	9.6	5.9	6.3	6.8
Repair of machinery	5.2	7.4	4.6	7.2	6.1

Note: Panel A shows the yearly compound productivity growth rate in 19 manufacturing sub-sectors in the Nordic countries between 2001 and 2014, expressed as TLC coefficients. Panel B shows the labour productivity level in 2014, expressed as TLC coefficients.

Source: WIOD and author's calculations.

(%). Panel B of Table 1 shows the TLC level for the final year of the period.

The table is rather self-explanatory, but a few points should be emphasized. First, the strongest productivity growth of the countries' average (Nordics) is found in pharmaceuticals, with a yearly reduction of the labour needed per unit of final demand of 8.0 per cent between 2001 and 2014. Paper and pulp is found at the other end of the spectrum, with a yearly produc-

tivity growth of 4.9 per cent. Second, when it comes to the productivity levels of the countries' average (Nordics) in 2014, with 1.5 employed persons per million dollar, coke and petroleum stands out, as it usually does. With a TLC level of 7.3 workers, the amount of labour needed is almost five times higher in printing and recorded media than in coke and petroleum. Finally, when comparing the rate of productivity growth, it is clear that Norway's strong per-

formance is broad based: In 17 of the 19 sub-sectors, the yearly growth rate between 2001 and 2014 was higher in Norway than the average for the four countries.<sup>24</sup>

To further explore the relative labour productivity performance among the Nordic countries, the most pronounced change in the TLC-ranking among the manufacturing sub-sectors is found in Norway.<sup>25</sup> Its average ranking in 2001 was 2.6, but in 2014 it had increased to 1.5 – an improvement of more than 40 per cent. Consequently, Norway has moved from being the second to last country to becoming the country with the best average ranking position. In 2014, Norway was the top ranked Nordic country in 13 sub-sectors, and first or second in 17 sub-sectors. The flip side of this strong performance is mainly that Sweden’s ranking has deteriorated substantially since 2001. In that year, Sweden was the leading Nordic country in terms of the average ranking position, but 13 years later the country was surpassed by both Norway and Denmark. For Denmark and Finland, the average rank was almost unchanged between 2001 and 2014. Denmark is still the second highest ranked country, and Finland is still lagging behind the other countries.

### **The Role of Imported Intermediate Inputs in Nordic Manufacturing Production**

One important aspect of Pasinetti’s –

gross output based – vertically integrated productivity is the use of imported intermediate inputs. Obviously, this aspect has become increasingly relevant in the wake of intensified vertical specialization and this is also apparent in the latest vertically integrated productivity research.<sup>26</sup> In this context, the reasonable hypothesis is that countries with a large import multiplier have a smaller domestic need for labour per manufacturing product, everything else equal, since a larger share of the necessary employment is embedded in the imported intermediates.

Using equation (3) – where direct import multiplier  $DIM$ , is a matrix containing each sector’s intermediate input imports per unit of gross output, and the column sum for sector  $i$  in period  $t$  in total import multiplier,  $TIM$  matrix, expresses the use of imports per unit of final demand – the import multipliers have been estimated for the Nordic countries (Dietzenbacher *et al.*, 2000).

$$TIM = DIM(I - A)^{-1} \quad (3)$$

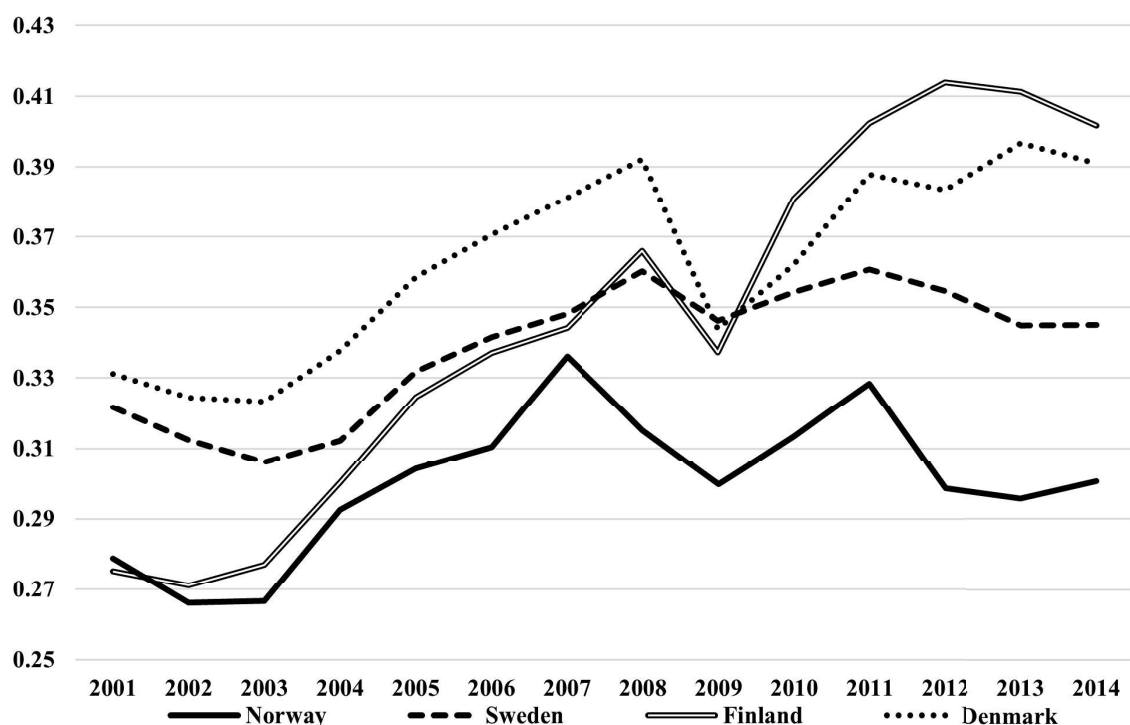
Chart 2 shows that manufacturing production in the Nordic countries since the turn of the millennium has become increasingly dependent on intermediate input imports. This means that for each unit of manufacturing final demand, there is a need for a larger share of imported in-

<sup>24</sup> If the productivity growth in the Nordics column is related to the Nordics TLC level in 2001, there is a slight divergence, with sub-sectors with a low TLC level in 2001 also showing an above average decrease in the labour needed to make a product.

<sup>25</sup> Each sub-sector in each of the four countries is ranked between 1-4 from highest to lowest.

<sup>26</sup> Timmer (2017), Timmer and Ye (2018, 2020), and Pahl and Timmer (2019).

**Chart 2: The Use of Imported Intermediate Inputs per Unit of Final Demand (Import Multiplier), the Aggregate Manufacturing Sector in the four Nordic Countries, 2001-14**



Source: WIOD and author's calculations

intermediate inputs in order to finalize the product.<sup>27</sup> This pattern has been particularly strong and uniform during the years up to the financial crisis. The result has been that a manufacturing product gradually generated less value added and employment in the domestic economy.

After an initial reduction of the import multiplier in connection with the financial crisis, the import dependency of manufacturing production has developed in different ways in the Nordic countries. Finland is the country that primarily stands out. In this case, the import dependency has continued to increase at the same rate as before the financial crisis, which has resulted

in the multiplier amounting to 0.4 in 2014. For Denmark, a considerable decrease in the import dependency in connection with the financial crisis has now rebounded to the same level as in 2008-09. For Sweden and Norway, the import multiplier is still lower than at the start of the financial crisis, but in both cases after an initial recoil back to the level before the crisis.

Finland's import multiplier has grown fastest among the Nordic countries since the turn of the millennium (46 per cent) from 27.4 per cent to 40.2 per cent. It has grown most slowly in Sweden (7.3 per cent) and Norway (7.8 per cent). Norway's modest increase in its share of intermedi-

<sup>27</sup> The level of imported intermediate inputs have been used as weights when creating the averages for the aggregate manufacturing sector.

ate goods imports in final demand over the 2001-2014 period is explained by the fall in this share after the financial crisis. Finland has thus moved from being a country with a low import dependency to being a country with a high import dependency. Norway's position as a country with a distinctively high dependency on domestic intermediate inputs has become more apparent.

The ensuing question from this analysis is: do the level and growth differences of the import multipliers of the Nordic countries affect the interpretation of vertically integrated productivity growth since the turn of the millennium? If we focus on the change between 2001 and 2014, it does not seem to be the case that the rate of reduction in the amount of labour needed in the domestic economy has been the highest in those countries with the largest increase in their intermediate import dependency. It has been quite the opposite. Despite having the strongest growth in the import multiplier, the Finnish reduction in labour needed in the domestic economy has been the lowest.

In the same spirit, the Swedish import multiplier has increased by one sixth of the Finnish import multiplier, but the reduction in the domestic need for labour per manufacturing product has been approximately as large in both countries. Third, Norway succeeded in achieving the highest domestic productivity growth despite, together with Sweden, having the slowest growth of the import multiplier. Altogether, this suggests that the vertically in-

tegrated productivity performance of Norwegian manufacturing improved relative to that of the other Nordic countries even if due consideration is given to how the intermediate import dependency has developed. The opposite is apparent for Finland.

### **The Role of Imported Intermediate Imports in Nordic Manufacturing Production: An Econometric Exercise**

The previous section supports the argument in the literature that it is important to explicitly include the import of intermediate inputs when empirically analyzing Pasinetti's total labour coefficients (Arena and Porta, 2012). The foundation of this argument is that large countries tend to import less intermediate inputs than small countries. However, this implied difference in the level of import multiplier should – as was also suggested in the previous section – be complemented with a time-dimension: to what extent do changes in the import multiplier affect the change of the domestic need for labour per unit of manufacturing product. In order to obtain a more statistically robust picture of the role of imported intermediates in a Pasinetti framework, an econometric exercise in this section is performed which explores both the cross-section (level, time-invariant) and the time dimension.<sup>28</sup>

Table 2 summarizes the results. When estimating the model that focuses on the level of imported intermediates (Be: be-

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<sup>28</sup> This exercise was inspired by Gu and Yan (2017), Timmer (2017), Criscuolo and Timmis (2018ab), Timmer and Ye (2018; 2020), Gal and Witheridge (2019), Jona-Lasinio and Meliciani (2019) and Acemoglu and Azar (2020).

**Table 2: Relationship between Total Labour Coefficients and Import Multipliers in Nordic Manufacturing Industries**

	2001-14			2001-08			2009-14		
	Model			Model			Model		
Dependent variable: TLC	Be	Fe	Re	Be	Fe	Re	Be	Fe	Re
Coefficient	-0.633	0.111	0.056	-0.622	0.181	-0.058	-0.507	-0.036	-0.092
Std. error	0.224	0.134	0.109	0.219	0.201	0.177	0.22	0.141	0.094
t	-2.74	0.82	0.51	-2.85	0.88	-0.33	-2.31	-0.26	-0.98
P> t	0.008	0.496	0.607	0.006	0.471	0.744	0.025	0.82	0.328
Sign.level	99%	NS	NS	99%	NS	NS	95%	NS	NS
Obs.	1064	1064	1064	608	608	608	456	456	456

Note: The table shows the correlations (elasticities) between the import multiplier and the total labour coefficient (TLC) in Nordic manufacturing production – after the control of three other, domestically oriented, variables: the capital multiplier, the human capital multiplier and the output multiplier. Following equation (2), the capital multiplier for each sub-sector is defined as the column sum of the matrix  $CAM = \frac{CapitalStock}{GrossOutput}(I - A)^{-1}$ , and the human capital multiplier is, accordingly, defined as the column sum of the matrix  $HCAM = \frac{Highskilledlabour}{Totallabour}(I - A)^{-1}$ , where high skilled labour is defined as individuals with a university degree. The output multiplier is defined as the column sum of the Leontief inverse, but excluding each sub-sector's intermediate inputs trade with itself. Sources: WIOD, EU Klems and author's calculations.

tween estimator<sup>29</sup>), meaning that it excludes changes over time, the result is clear and intuitive: a large average import multiplier is strongly associated with a low average total labour coefficient. Hence, the more imports that are used in the production process, the less domestic labour is needed to finalize the product. This holds for the whole period and for the two sub-periods. As the data used in these estimations is in log-log format, the coefficient of -0.633 indicates that we can expect a 0.63 per cent lower average labour productivity level with a one per cent higher average import multiplier.<sup>30</sup> For the whole period and before the financial crisis, this correlation is

significant at the 99 per cent level, but falls back to the 95 per cent level between 2009 and 2014.

When estimating the model which concentrates on the time dimension of the data (Fe: fixed effect/within estimator<sup>31</sup>), the result is equally clear: there is no correlation between the changes of the import multiplier over time and the changes in Pasinetti's total labour coefficients.<sup>32</sup> This is true for the whole period and for the two sub-periods. This means that any change in the use of imported intermediate inputs in the production process does not give any information on the change in the to-

29 The Be-estimator runs an ordinary least square model based on the average of each variable over the time period.

30 This elasticity is larger than the absolute value of the import multiplier, suggesting that the use of imported intermediates is productivity enhancing.

31 The Fe-estimator runs the regression on each variable's difference between its yearly value and its average value over the time period.

32 NS means not significant at the 95 per cent level. To give the model somewhat of a causal interpretation, I have experimented with time lags of the control variables. These do not alter the results. The within and random effect estimations are adjusted for (robust) clusters.

33 However, this does not exclude the possibility that changes in the composition of the imported intermediates have had an effect on the domestic need for labour per manufacturing product.

tal labour coefficients.<sup>33</sup>

Finally, when estimating the model which combines the cross-sectional and the time dimension (Re: random effect), the result is also clear: there is no correlation between the import multiplier and the TLC.<sup>34</sup>

### Supply Chain Productivity in Nordic Manufacturing Production

From a theoretical point of view, the vertically integrated productivity perspective more closely resembles real world production than the conventional, sectoral-based perspective, since trade in intermediate inputs, nationally and globally, is an essential part of any production system with any degree of specialization. From an empirical point of view, the previous section connected the use of imported labour – embodied in the intermediate inputs – with the domestic use of labour. By splitting the domestic production chain into separate parts, a similar connection can be made within the domestic economy. The main question then becomes the following: to what extent do different segments of the domestic production chain contribute to the reduction of Pasinetti’s total labour coefficients?

In order to explore this empirically, I create two vertically oriented – but this time, value added based labour productiv-

ity measures. This is done using the following two matrices (vertical value added (VVA) and vertical employment(VEMP)):

$$VVA = \frac{VA}{GO}(I - A)^{-1}FD \quad (4)$$

$$VEMP = \frac{EMP}{GO}(I - A)^{-1}FD \quad (5)$$

Each column sum in *VVA* and *VEMP* expresses the total value added and employment, respectively, needed somewhere in the domestic economy to satisfy each sector’s final demand, including all subsequent rounds of intermediate demand. Consequently, if the value added and the employment generated within each sub-sector’s “own” sector is excluded (e.g the value added and employment generated in motor vehicles from the final demand for motor vehicles),<sup>35</sup> the labour productivity of the sub-sector’s domestic supply chains can be estimated. This is called supply chain productivity. “Own” productivity is identical to conventional, sectoral-based labour productivity.<sup>36</sup>

Table 3 summarizes the relation between these two productivity measures. Three conclusions emerge. First, in some sub-sectors, the productivity level is higher

<sup>34</sup> The Hausman test shows that the fixed effect model is a more appropriate model than the random effect (Re) model.

<sup>35</sup> With a matrix language, Miller and Lahr (2009) define these “own” sectors as the on-diagonal elements, or the internal linkages.

<sup>36</sup> OECD (2001) argues that sectoral, value added based labour productivity is the most common productivity measure. This is thus a measure which focuses on separate sectors as they are defined in the national accounts and excludes the intermediate inputs that are used in the sector’s production processes. The productivity of the whole domestic production process is just the weighted sum of the sectoral and the supply chain productivities. In practice, this can be found by dividing each sub-sector’s column sum in *VVA* with its corresponding column sum in *VEMP*.

**Table 3: Two Labour Productivity Measures in Nordic Manufacturing Production, Levels and Changes, 2001-14**

	2001		2014		$\Delta$ 2001-14 (%)		Supply Chain/ Sectoral	
	Sectoral	Supply Chain	Sectoral	Supply Chain	Sectoral	Supply Chain	2001	2014
Food, beverage, tobacco	51.2	40.0	108.0	90.6	5.9	6.5	0.78	0.84
Textile, clothing, leather	36.9	55.4	78.8	122.3	6.0	6.3	1.50	1.55
Wood and cork	46.8	63.7	80.5	126.9	4.3	5.4	1.36	1.58
Paper and pulp	91.4	65.8	132.7	134.2	2.9	5.6	0.72	1.01
Printing and recorded media	47.7	65.1	86.5	130.2	4.7	5.5	1.36	1.50
Coke and petroleum	145.0	115.9	187.6	324.7	2.0	8.2	0.80	1.73
Chemicals	98.0	60.1	241.4	176.6	7.2	8.6	0.61	0.73
Pharmaceuticals	119.9	57.9	338.3	169.6	8.3	8.6	0.48	0.50
Rubber and plastics	52.4	58.7	109.5	126.7	5.8	6.1	1.12	1.16
Other non-metallic	50.6	59.2	114.7	146.3	6.5	7.2	1.17	1.27
Basic metals	75.8	60.4	122.7	138.8	3.8	6.6	0.80	1.13
Metals, except machinery	47.5	58.1	98.3	128.1	5.8	6.3	1.22	1.30
Computer and electronics	109.2	53.9	225.2	117.0	5.7	6.1	0.49	0.52
Electrical equipment	57.2	56.2	131.1	118.0	6.6	5.9	0.98	0.90
Machinery and equipment	56.1	54.3	151.7	117.4	7.9	6.1	0.97	0.77
Motor vehicles	56.0	57.2	126.4	121.0	6.5	5.9	1.02	0.96
Other transport (e.g ships)	50.9	55.6	130.7	128.1	7.5	6.6	1.09	0.98
Furniture	47.2	55.7	99.6	119.0	5.9	6.0	1.18	1.19
Repair of machinery	46.8	55.9	109.2	121.4	6.7	6.2	1.19	1.11
Average	67.7	60.5	140.7	139.8	5.8	6.5	0.89	0.99

Note: The average is unweighted. Changes over time, ( $\Delta$  2001-14 (%)), are defined as the annual compound growth rate. Productivity levels are expressed in thousands of constant US dollars of value added per person engaged. Source: WIOD and author's calculations.

from the sectoral than from the supply chain perspective, but in other sub-sectors the opposite is the case.<sup>37</sup> The last column shows that the largest positive difference for the supply chain measure in 2014 is found in coke and petroleum and Wood and cork, respectively.<sup>38</sup> In terms of the sectoral measure, the largest positive difference is found in pharmaceuticals and computer and electronics, respectively.

Second, in 2001 the supply chain productivity level did, on average, reach 89 per cent of the sectoral productivity level (i.e. 60.6/67.7). Due to a stronger supply chain

productivity growth until 2014, there was a convergence between the two measures – leading to the conclusion that in 2014, the average level of productivity within the Nordic manufacturing production system is more or less the same in terms of sectoral and supply chain productivities (i.e. 139.8/140.7).

Third, the table indicates that the Spearman rank correlation between the two measures is rather weak. At a closer inspection, the rank correlation in 2001 amounted to 0.2, and in 2014 it had increased slightly to 0.25.

<sup>37</sup> As can be seen from the table, the standard deviation is lower for the supply chain productivity. The reason for this is that the manufacturing sub-sectors use similar types of intermediate inputs to a substantial extent.

<sup>38</sup> If the sectoral productivity is compared to Pasinetti's total labour coefficients, a few sub-sectors also stand out. For example, in 2014 computer and electronics improves its rank with five positions and printing and recorded media with four, when productivity is measured in value added terms instead of the total labour coefficients. Metal, excluding machinery, goes in the other direction to a similar extent. Other sub-sectors with a non-negligible difference between the two measures are basic metals, furniture and repair of machinery, respectively.

**Table 4: Relationship between Total Labour Coefficients, Sectoral Productivity, Supply Chain Productivity and Import Multiplier in Nordic Manufacturing Industries**

	2001-14			2001-08			2009-14		
	Model			Model			Model		
Dependent variable: TLC Coefficients/elasticities	Be	Fe	Re	Be	Fe	Re	Be	Fe	Re
Sectoral productivity	-0.613	-0.244	-0.303	-0.600	-0.424	-0.468	-0.578	-0.170	-0.236
Supply chain productivity	-0.749	-0.777	-0.721	-0.650	-0.622	-0.574	-0.807	-0.765	-0.774
Import multiplier	-0.475	-0.388	-0.441	-0.447	-0.383	-0.425	-0.553	-0.430	-0.492

Note: The table shows the correlations (elasticities) between three variables and Pasinetti’s total labour coefficient (TLC) in Nordic manufacturing production. There were 1064 observations in 2001-14, 608 in 2001-08 and 456 in 2009-14

Source: WIOD, EU Klems and author’s calculations.

### Supply Chain Productivity in Nordic Manufacturing Production: An Econometric Exercise

With the two value-added based productivity measures analyzed in the previous section, it is possible to increase our understanding of the main forces behind Pasinetti’s total labour coefficients. Therefore, in this section, the variation in TLC is explained by three separate parts of the manufacturing production process: (1) the sectoral productivity, (2) the supply chain productivity, and (3) the import multiplier. The main purpose of this set up is to answer the question: what is the relative contribution of these two productivity measures to the variation in Pasinetti’s total labour coefficients?

Using the same econometric approach as before, we can expect very high R2-values, t-values and significance levels, as we are studying correlations between related productivity measures.<sup>39</sup> The main result from Table 4 is that a 1 per cent change in the supply chain productivity indicates a substantially larger effect on

Pasinetti’s TLC’s than the same change in sectoral productivity, regardless of which model is estimated and what period is studied. For example, with the preferred Fe-model, and during the period 2001-14, a 1 per cent change in the supply chain productivity increased TLC by 0.78 per cent, but only by 0.24 per cent in terms of sectoral productivity.

This shows that a vertically integrated perspective, with a distinction between “own” and supply chain productivity, can give us new insights into the main drivers behind changes in Pasinetti’s total labour coefficients – or the amount of labour needed in the domestic economy in order to finalize a manufacturing product. Finally, Table 4 indicates that the sectoral productivity performs relatively better with the Be-estimator; hence, when the time dimension is not considered, and the regressions are based on each variable’s average value over the period. Consequently, this implies that the sectoral productivity measure is relatively worse in explaining the development of Pasinetti’s total labour coefficients

<sup>39</sup> Naturally, this indicates a strong reversed causality. The level of significance in all model estimations in Table 4 is above 99.9 per cent. The overall R2-values are often above 0.9, but in general they are decreasing after the financial crisis. The data used in the estimations is in log-log format. The Hausman test shows that the Fe-model is the appropriate model. The within and random effect estimations are adjusted for (robust) clusters. Using one and two time lags of the independent variables does not alter the results.

since the millennium. As can be seen from the table, this is especially the case after the financial crisis. During this period, the contribution to the variation in TLC is even more than twice as large for the import multiplier than for sectoral productivity.

## Conclusion

### Contributions and Main Results

The starting point of this article is that specialization, within and between countries, and an increased importance of knowledge-based capital in current growth processes, have led to a renewed interest in a vertically integrated perspective on productivity. This article contributes to this renewed interest by the use of Pasinetti's total labour coefficients in the context of Nordic manufacturing production. A second contribution of this article is the empirically based discussion of the contributions of the vertically integrated productivity perspective to the understanding of the current growth process among trade-dependent and highly specialized countries.

The main results are the following. Among the Nordic countries, Norway has improved its relative manufacturing productivity since the millennium, and this improvement is broadly based among the manufacturing sub-sectors. When the change in the use of imported intermediate inputs is considered, the strong Norwegian performance becomes even clearer. The flip side of this is that Sweden, on the relative scale, has lost its position as the productivity leader to Norway, and has also been surpassed by Denmark. However, on an absolute scale, it is clear that Finland's performance after the financial crisis has been

particularly poor, and this is exacerbated if the rapid growth in the use of imported intermediate inputs is taken into account; despite the fastest growth of the import multiplier among the Nordic countries, the reduction in the domestic need for labour was the slowest.

This rather counterintuitive relation between the change in the use of imported intermediates and the change in the use of labour in the domestic economy is confirmed econometrically. Within the Nordic manufacturing production system, the development of the use of imported intermediates cannot say anything statistically significant about the rate of change in the amount of labour needed in the domestic economy in order to finalize a product. However, when the regressions are based on the time period average – and, hence, excluding any change in the variables during the time period – a large import multiplier is strongly associated with a low total labour coefficient.

To further investigate the main drivers behind Pasinetti's total labour coefficients, an empirical distinction is made between the conventional, sectoral based labour productivity measure and a productivity measure based on the domestic supply chain. With this approach, it is shown that the rank correlation between the two measures is low and that the latter has converged to the same level as the former since the millennium. Along these lines, an econometric exercise shows that the absolute contribution to the total labour coefficient is considerably greater in terms of supply chain productivity than in terms of sectoral based productivity. Predicting changes in Pasinetti's total labour coeffi-

cients without the vertically integrated perspective would thus leave out relevant information.

### **Some Policy Aspects**

What is required to reverse the weak labour productivity growth that we have seen in the Nordic countries and the rest of the Western world after the financial crisis? At a fundamental level, this is, of course, about well-functioning markets, free trade and a modern infrastructure. Taking the starting point that Nordic manufacturing production is at the technological front, I would, however, like to emphasize the importance of a well thought out innovation policy and how such a policy contributes to moving the frontier.

In a recent survey of the research on policies to improve innovation, Bloom *et al.* (2019) consider that certain measures are indeed efficient in the short run, while others are more efficient in the long run and the political system tends to focus too much on the short run. In the short run, tax incentives for and public funding of R&D are of crucial importance but the longer is the perspective, the larger should the focus be on human capital – on how the quality of the production factor labour can be improved. This means that the educational system and its role for life-long learning should be given higher priority and that the responsibilities for employers increase in this respect. This also includes improving the quality of higher education and reforms to attract highly skilled labour from abroad. In Sweden, the resources the government spends on each university student has decreased by 30-50 per cent since the 1990s.

In addition, productivity-enhancing policies, according to the OECD (2015, 2016), should become more “holistic”. For example, this includes considering the fact that growing income differences can damage the productive base of the economy and that low-wage jobs reduce aggregate productivity. Moreover, resource allocation is improved if the equality of educational opportunities increases, discrimination is pushed back and the social mobility moves in the right direction. A high level of well-being at work is productive and profitable.

Another aspect that should be pointed out in this context is that the rate of diffusion of new technology and knowledge within countries seems to have fallen, with the consequence that the productivity difference between globally oriented firms and other firms have increased. What should be achievements that all firms can invest in and benefit from, such as automatization connected to artificial intelligence, have so far mainly benefitted certain parts of the business sector. This leads to questions on how receptive domestically-oriented firms are to developments that mainly take place in globally oriented firms, but also to what extent new technologies are firm-specific and can only be spread to other firms with considerable supplementary investments.

This diffusion has become increasingly important since a larger share of the “capital” generating productivity growth is defined as intermediate inputs and is therefore distributed in the economy through the intermediate input structure. Accordingly, an important aspect for individual firms is to, as a subcontractor, connect to globally oriented firms. Becoming an indirect exporter is – in the light of the resources

that are required and the difficulties that smaller firms might meet in their export venture – often good enough and beneficial to the economy in the same way as exporting on their own. Considering their central role as a subcontractor and their importance for the contemporary growth process, the knowledge-intensive business services constitute a key to the Nordic countries as future manufacturing nations. It is not about the manufacturing sector or the service sector – it is about both.

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# What Do We Know About Economic and Productivity Growth? A Review Article on *Measuring Economic Growth and Productivity: Foundations, KLEMS Production Models, and Extensions*

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## ABSTRACT

*Measuring Economic Growth and Productivity* is not only a book on an essential topic, namely that of “growth and productivity”, it is also a fabulous ensemble, bringing together contributions from many top specialists. But, in addition, it is a tribute to Dale W. Jorgenson, who has for decades been an exceptional contributor to gaining a better knowledge of the mechanisms of growth and productivity. The volume is dedicated to him. I was present in January 2020 at the annual IPM dinner at the AEA conference, when a preprint of the book was presented to him by the editor, Barbara Fraumeni. I openly admit that it was a very emotional moment.

Economic growth and productivity measurement are of principal concern for policy makers and economists, among others. Productivity growth is one of the main sources of economic and real income growth needed for improvements in well-being. A vast literature has been devoted to this topic over the last decades and even centuries. But there is still much to do to better understand the mechanisms of growth.

Dale W. Jorgenson, Samuel W. Morris University Professor in the Department of Economics at Harvard University, is one of the main economists to have contributed to a better understanding of these growth mechanisms. The volume under review, *Measuring Economic Growth and Productivity: Foundations, KLEMS Production Models, and Extensions* is dedicated to

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him.<sup>2</sup> As the volume editor, Barbara Fraumeni, Special-term Professor at the China Centre for Human Capital and Labor Market Research of the Central University of Finance and Economics in Beijing, China, writes in the introduction to the volume,<sup>3</sup> “The chapters of this book demonstrate the significant influence of Dale W. Jorgenson on the research of many economists”. No one researcher in this field can ignore the name of Dale Jorgenson and at least some of the papers from him. But his academic production has been so abundant and varied that no one (other than himself perhaps) can pretend to completely know his large and deep contribution.

This book is a compilation of 22 articles (excluding the Introduction) written by 58 authors totaling over 536 pages. Most of the articles use data from the World KLEMS database, an enlargement of EU KLEMS, and the fruit of a three-decade old project, which has been continuously supported by Jorgenson (see, for instance, Jorgenson, 2012). Numerous dimensions of economic growth and productivity measurement are treated in this compilation. We comment on different chapters of the book, grouping them into the four topics: foundations, international comparisons, country-specific analyses, and methodological issues, before concluding the review with some general remarks.

## Foundations

The volume begins with three chapters on foundations. Using long-term data for the United States, Edward A. Hudson shows the essential role of demand in growth mechanisms. He emphasizes the role of innovation and the contribution of the Schumpeterian concept of “creative destruction”. What might surprise the reader is that the ground-breaking contribution from Aghion and Howitt on this topic is not mentioned.<sup>4</sup>

J. Steven Landefeld describes the interaction between economic theory, research and the development of the US national accounts. He discusses improvements in national accounts which take into consideration this interaction, including better measurement of economic welfare, such as supplementary accounts on the distribution of income, natural resources and the environment, and the development of a set of sustainability measures.

Kun-Young Yun presents the Dynamic General Equilibrium Model that he developed with Jorgenson in 1986 on the US economy to evaluate the welfare effects of tax policy and government spending. They found with this tool that taxation of capital income is the most expensive compared to other forms of taxation in terms of the efficiency cost per dollar of tax revenue.

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2 The volume was published in November 2019 by the Academic Press of Elsevier, ISBN: 9780128175965, USD\$125.00. The table of contents is available at <https://www.sciencedirect.com/book/9780128175965/measuring-economic-growth-and-productivity>.

3 The associate editors are Carol Corrado, Mun S. Ho, Hak K. Pyo, and Bart van Ark.

4 For instance, among numerous ones, Aghion and Howitt (1992, 1998, 2009).

## International Comparisons

Khuong M. Vu compares the economic growth performance of the E7 economies (the 7 largest emerging countries, namely China, India, Indonesia, Brazil, Mexico, Turkey and South Korea) to that of the G7 economies over the 2000-2017 period. In 2017, the two country groups represented respectively 37 per cent and 31 per cent of world GDP, while GDP per capita was on average in the E7 countries only 26 per cent of that in the G7 countries. But the E7 countries are (except Mexico) in a fast catch-up process; due to higher capital accumulation and total factor productivity (TFP hereafter) growth, their contribution to world growth is 60 per cent compared to less than 20 per cent for the G7 countries.

Robert Inklaar, Kirsten Jäger, Mary O'Mahony and Bart van Ark analyse the supply factors of European growth compared to the United States between 1995 and 2015. They show that both in Europe and in the United States, information and communication technologies (ICT) have significantly contributed to productivity growth, but they admit not to be able to explain the general productivity slowdown. It seems to them that we are still “in the midst of the transition from the Old Digital Economy (which was characterized by the introduction of the PC in people’s lives and business processes, the rise of the internet, and the beginning of the e-commerce) to the New Digital Economy (which is characterized by the change toward mobile, ubiquitous access to the internet, the storage and usage of data, and advances in artificial intelligence and robotics)”.

Chi-Yuan Liang and Ruei-He Jheng com-

pare TFP changes in the ICT industry among Japan, Korea, Taiwan, China and the United States. They show that during 1981-2010, lower R&D spending, fewer and lower-quality patents have led to lower TFP growth in the ICT industry in Taiwan, Korea and China compared to that of the United States and Japan.

Kyoji Fukao, Tsutomu Miyagawa, Hak Kil Pyo, Keunhee Rhee and Miho Takizawa compare the impact of information and communication technology investment on employment in Japan and Korea. They show that in both countries, this impact depends on the skill level of the workforce.

Matilde Mas, André Hofman and Eva Benages propose an international comparison of knowledge-based human and physical capital services over the 2000-2015 period. More developed countries appear to have a higher share of knowledge-based capital services in total capital services, but the knowledge-based economy is growing faster in less developed countries, which represents a convergence process.

## Country-Specific Analyses

K.L. Krishna, Bishwanath Goldar, Deb Kasum Das, Suresh Chand Aggarwal, Abdul A. Erumban and Pilu Chandra Das analyse the Indian growth performance. It appears to them that while economic reforms undertaken in India since 1991 had a positive impact on productivity performance in the manufacturing sector, there are still many reforms to implement to boost productivity growth in manufacturing and also in other sectors of the economy.

Harry Wu analyses the origins of the pro-

ductivity slowdown in China. He shows that the TFP slowdown starting in the early 2000s was a consequence of its WTO entry in 2001 because of the increase in state interventions to protect strategic industries. He points out that capital resources were increasingly directed to selected state industries and crowded out more efficient private enterprises.

Gang Liu analyses the growth factors in Norway during the period 1997-2014. The productivity slowdown in that country came from slower growth of TFP and capital deepening, and the two industries which contribute the most are finance and distribution services.

## Methodological Issues

Ilya Voskoboynikov, Derek Burnell and Thai Nguyen report on the progress of the World KLEMS project in Australia and Russia. These two countries seem to be now well-covered by the World KLEMS database, which offers new research opportunities to economists.

Lucy Eldridge, Corby Garner, Thomas Howells, Brian Moyer, Matthew Russell, Jon Samuels, Erich Strassner and David Wasshausen discuss how the US Bureau of Economic Analysis (BEA) and Bureau of Labor Statistics (BLS) have developed “a complete integrated industry-level production account for the United States that combines output and intermediate inputs data from the BEA GDP by industry accounts with measures of labor and capital inputs from the BLS productivity program”. The authors of this chapter are from the two institutions (BEA and BLS). Such an outstanding project in the US sta-

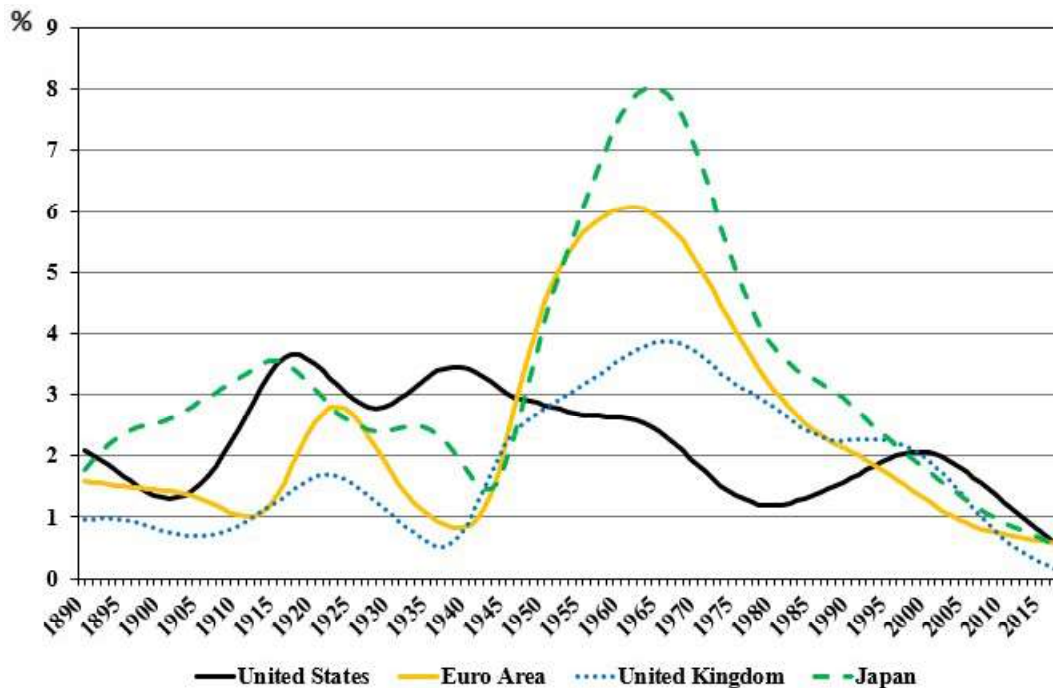
tistical system must of course be congratulated.

Koji Nomura, Kozo Miyagawa and Jon Samuels provide new benchmark estimates of Japan-US industry-level price differentials for 2011, based on a price accounting model.

Marshall Reinsdorf and Paul Schreyer address the question of measuring consumer inflation in a digital economy. They deal with three problems: incomplete adjustments for quality change in products or distribution channels; neglected welfare gains or costs savings from truly novel digital products; and neglected welfare gains from free digital products. They calibrate their evaluation at the upper bound and find that in OECD countries, the products concerned accounted for about 35 per cent of household expenditure in 2005, declining to 32 per cent in 2015. In the new measurement they propose, the consumption deflator would be lowered by 0.6-0.7 percentage points. This gives “a more optimistic picture of growth and productivity changes but would not overturn the conclusion that productivity has slowed substantially”.

Carol Corrado, Jonathan Haskel, Massimiliano Iommi and Cecilia Jona-Lasinio develop a theoretical framework to analyse the relationship among intangibles, innovation, and productivity by building a Jorgenson-like model of economic growth. They also provide empirical evidence for the United States and selected European countries. They show that the growth of intangible capital recovered faster after the Great Recession than did tangible capital, and that there is a positive relationship between intangible capital growth and TFP growth, whereby the decline in intangible

Chart 1: Total Labour Productivity Growth in the United States, the Euro Area, the United Kingdom, and Japan, 1891-2018  
Smoothed indicator (HP filter,  $\lambda = 500$ ) – average annual growth rate in output per hour



Source: Bergeaud, Cette and Lecat (2016) - See: [www.longtermproductivity.com](http://www.longtermproductivity.com)

capital growth explains more of the decline of TFP growth in the United States than in Europe.

Ana Aizcorbe, David Byrne and Daniel Sichel propose a new price index for smartphones which is better quality adjusted than the official index, and a methodology for disentangling the spending on phones and wireless services when the two are bundled together. Their adjusted deflator of Cellular Telephone Services fell about 4 percentage points faster per year than currently published measures over the last two decades. Their “results highlight the rapid decline in quality-adjusted prices for products related to the digital economy and, by implication, continued rapid technical advance in these products”.

Marcel Timmer and Xianjia Ye propose to take into account global value chains in

growth and productivity accounting.

Two chapters of the book deal with the topic of climate change. Richard Goettle, Mun Ho and Peter Wilcoxon propose an approach for taking into account emissions and carbon tax in computable general equilibrium models. Jing Cao, Mun Ho and Wenhao Hu propose an empirical application of such an approach on China.

Daniel Slesnick revisits the issue of social welfare, using US regional data provided by the BEA concerning different possible welfare components.

## Conclusion

This collected volume is targeted to economists and policy makers who are interested in gaining a better understanding of questions related to growth and pro-

ductivity. It provides abundant food for thought and the impetus to carry out analyses on these topics. References to Jorgenson's publications are plentiful, which indicates the extent to which he is an unprecedented pioneer on so many questions. This book is a beautiful and well-deserved tribute to him!

One criticism of the volume is that chapters do not appear to be structured in a logical manner. To assist the reader of the review article, I have attempted to present the chapter in a more logical order.

A first remark on the content is that, after having read the volume, one is still looking for an explanation of the reasons why we see ICTs and digital technologies everywhere except in the productivity growth statistics. Productivity growth has slowed down over recent decades in all developed countries, whatever their distance to the technological frontier, their institutions, and their levels of ICT use (Chart 1). For more than a decade, labour productivity growth has been at rates never observed for at least one and a half centuries. This reminds us of the well-known words from Robert Solow (1987) "You can see the computer age everywhere, but in the productivity statistics".

As suggested in some analyses (e.g. Brynjolfsson and McAfee (2014), van Ark (2016), Branstetter and Sichel (2017), or in Inklaar, Jäger, O'Mahony and van Ark (2019)), perhaps this puzzle corresponds once again to what happened in previous technological revolutions: the profound changes were only diffused gradually, and their impact on productivity performance was not felt until decades later. Paul David has shown that between 50 and 60 years

passed between the invention of a working electric dynamo in 1868 and its full exploitation in production (in the 1920s to 1930s). If we extrapolate that, it will always take a long time for the full impact of a technological revolution to be seen in productivity statistics. We have to hope that this explanation is the right one, and that we will benefit in future years or decades from a productivity revival. Otherwise, developed countries will struggle to face the numerous challenges of the future. These challenges, which Gordon refers to as headwinds (see for instance, among many papers, Gordon, 2015), are significant. They include population ageing, climate sustainability, the reduction of public debt, and expectation of purchasing power increases. Moreover, without sufficient productivity growth to oil the wheels of the economy, the political risks to our democracies would inevitably increase.

A second remark on the content concerns the TFP. Is it always a relevant indicator to evaluate technological progress? We find in the literature and in this volume many factors affecting TFP growth including institutions, education, innovations, and factor allocation. We could easily obtain the impression that all together, these factors explain more than what we have to explain! As raised by Jorgenson and Griliches (1967), notionally, if the production function is perfectly specified, if all productive factors are well measured and taken into account, TFP measurement through the Solow residual approach should be small and would mostly correspond to the impact of externalities. Knowing then that TFP growth represents a "measure of our ignorance" (Abramovitz, 1956), perhaps when

we look at productivity growth, we should merely consider simple average labour productivity indicators.

But let me repeat here once again that this book is a precious compilation, useful to anyone who is interested in gaining a better understanding of growth and productivity mechanisms, and is an honorable tribute to Dale W. Jorgenson.

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# The Impact of Digitalization on the Economy: A Review Article on the NBER Volume *Economics of Artificial Intelligence: An Agenda*

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## ABSTRACT

Digitalization is affecting every aspect of our economy and our society. A set of new technologies are behind this latest surge - robotic process automation, artificial intelligence (AI) and machine learning (ML), big data, cloud computing, the internet of things and blockchain. This volume, *The Economics of Artificial Intelligence*, focuses on the impact, real and prospective, of machine learning (ML), on the economy. The authors tackle a wide range of topics, including how it is impacting innovation, the consequences for employment and economic growth, issues related to privacy, international trade and ultimately, how AI will affect the economics discipline itself. The contributors, overall, take a positive view of the impact of AI on economic outcomes. They also acknowledge, however, that policies related to redistribution, privacy and competition are needed to ensure that the benefits of digitalization are shared appropriately.

Digitalization is affecting every aspect of our economy and our society. A set of new technologies are behind this latest surge – robotic process automation, artificial intelligence (AI) and machine learning (ML), big data, cloud computing, the internet of things and blockchain. As these technologies became commercially viable, businesses are able to provide new products and

services, while reshaping how they operate. This volume, *The Economics of Artificial Intelligence: An Agenda*<sup>2</sup> published in 2019 by the University of Chicago as part of the National Bureau of Economic Research research volume series and edited by Ajay Agarwal, Joshua Gans and Avi Goldfarb, all at the University of Toronto, focuses on the impact, real and prospective, of arti-

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<sup>2</sup> ISBN: 978-0-226-61333-8, USD\$130.00. The table of contents is available at <https://press.uchicago.edu/ucp/books/book/chicago/E/bo35780726.html>.

cial intelligence (AI), and specifically machine learning (ML), on the economy. The authors tackle a wide range of topics, including defining artificial intelligence and machine learning, how it is impacting innovation, and the consequences for employment and economic growth. The volume also explores important issues related to privacy, international trade and ultimately, how AI will affect the economics discipline itself.

The grand debate is whether AI will be a large net benefit for the economy, and ultimately, to society. Will ongoing digitalization lead us to a world more like Star Trek or Bladerunner? The contributors, overall, take a positive view of the impact of AI on economic outcomes. They also acknowledge that policies are needed to ensure that the benefits of digitalization are shared appropriately. It should be noted that some of the authors use AI and ML interchangeably.

The review unfolds as follows. The first section discusses whether AI/ML can be considered a General Purpose Technology and its importance for innovation. From there, the second section tackles the main issues related to the impact of ML on economic growth, employment and inequality. Policy issues are addressed in the third section, including privacy and competition. The fourth section looks at the implications for the discipline of economics. The review concludes with some suggestions for further investigation – specifically, competition and the rise of super-star firms.

## **Artificial Intelligence as a General Purpose Technology**

The volume begins with an overarching summary of the existing debate on the impact of AI on economic growth by Erik Brynjolfsson, Daniel Rock and Chad Syverson. Their chapter, entitled “Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics”, explores why artificial intelligence is so important for economic growth, and the paradox that currently exists. The facts are well-known. Labour productivity growth slowed dramatically from 3 per cent annually in the 1950s and 1960s, to just over 1 per cent through the 1970s and 1980s. It picked up again with the advent of the internet and further gains in computing power from roughly 1995 to 2005. However, labour productivity has since slowed again to about 1 per cent. This slowdown has occurred even though a new range of technologies, and especially artificial intelligence, has burst onto the scene.

The authors highlight this simple paradox – if artificial intelligence is everywhere and a societal game-changer, why isn't it showing up in the productivity data? This play on Solow's famous quote on productivity is not unintentional. The authors then offer some possible explanations. First, while AI is very important for some sectors in the economy, it just might not deliver the expected productivity gains elsewhere. That said, the authors remain optimistic that AI will prove out as an economy-wide game-changer.

Second, the issue of mismeasurement is raised. It is widely recognized that official statistics are not able to keep up

with advances of technology and so actual productivity growth may be much higher than measured productivity. Nevertheless, the authors point to a series of studies to show that measurement bias cannot explain the productivity slowdown. In this regard, the volume in my view pays inadequate attention to the measurement issue. There are three shortcomings that stand out. First, there is evidence that while not initially measured, the productivity gains of the 1990s were only truly appreciated after historical revisions (Poloz, 2019). This may also be happening in the current context. Second, more attention is needed on highlighting exactly where the shortfalls in measurement methodologies or techniques are likely to be occurring. For example, official statistics are slow to include investments in data, data bases and data science, and in quality adjusting many of the digital services we now consume voraciously. Third, the authors note that the market power of large firms may be the culprit (as monopoly reduces the quantities supplied), but again remain unconvinced.

Instead, the most likely explanation is that, as a “General Purpose Technology” (GPT), it simply takes time for a technology like AI to diffuse through the economy. At the firm level, transformational GPTs require not only introducing the new tech, but also a completely new way of running a business. Consequently, it takes time, especially for incumbents, to adopt to the new ways of working. In the meantime, measured productivity will be low as investments are made and returns are initially slow to arrive. They point to the experience of previous GPTs to reinforce this point. Importantly, they make the simple

empirical point that current and past productivity trends do not predict future productivity growth.

The section then dives more deeply into what exactly is Artificial Intelligence and why it matters for innovation. Matt Taddy’s “The Technological Elements of Artificial Intelligence” provides a clear explanation of what is meant by AI. AI is not what is typically imagined in movies and popular conscience - machines thinking and acting like humans. AI is much more limited in the context of this volume to machine learning. Taddy usefully divides ML into General Purpose Machine Learning, Deep Learning and Reinforcement Learning. In each, a technical explanation is provided, but for the average reader the technical details are at times inaccessible. Greater use of concrete examples of how each type of technology is being used commercially would have been helpful.

The focus then turns to a simple question – if AI can lead to making better predictions at a lower cost, what role is there for humans in the process of decision-making? Ajay Agarwal, Joshua Gans and Avi Goldfarb’s “Prediction, Judgement and Complexity: A Theory of Decision-Making and Artificial Intelligence” sets out a model to show that, in fact, humans may be even more important in an AI-rich world. The model is simple: if the cost of prediction falls, then the value of its complements must rise. They argue that judgement is a complement and so demand for it will rise commensurately. How we can ensure that we bring the correct amount of judgement to an issue remains a topic for future research.

The rest of the section explores the im-

part of AI on innovation. Iain Cockburn, Rebecca Henderson and Scott Stern, in their chapter “The Impact of Artificial Intelligence on Innovation: an Exploratory Analysis”, show that AI, and especially machine learning, is likely to have a wide-ranging impact on how innovation is done. This is because it has the potential to be an “invention of a method of a method of invention” (Griliches, 1957). Specifically, AI-based learning will lower the cost of innovation by “automating discovery” and expanding the set of research and innovation opportunities that can be considered. They go on to document the incidence of AI in research output across disciplines and countries. Important lessons are also drawn - to make full use of ML, access to data is key, as well as appropriate competition and intellectual property policies. How AI can improve innovation is taken up by Ajay Agarwal, John McHale and Alexander Oettl in the follow-on chapter, “Finding Needles in Haystacks: Artificial Intelligence and Recombinant Growth”. In their view, AI can help to overcome the “burden of knowledge.” AI augments the ability of the researcher to combine new and existing knowledge in ways that were simply not possible before.

The last chapter of the section, “Artificial Intelligence as the Next GPT: A Political-Economy Perspective” offers thoughts on the political economy of technological disruption from AI. Manuel Trajtenberg focuses on the notion that there will be winners and losers of the coming transformation, and that governments will need to take appropriate action to support those workers who are displaced. Specifically, more focus will need to be paid to

soft skills, above and beyond the standard need for STEM skills, if the employment prospects of the displaced are to be enhanced. While providing some useful analysis, it is not clear how this chapter fits within the theme of the first section, which is AI as a GPT, and would more naturally be part of the next section.

## **Growth, Jobs and Inequality**

When most people talk about the coming impact of AI on the economy, most of the attention is naturally focused on jobs. That is, will robots render humans superfluous in the production process, leading to wide-spread job losses and the societal ills that accompany such disruption? At the very least, ongoing automation of routine manual tasks, and the more recent automation of routine cognitive tasks, will exacerbate existing trends of stagnant real wages for many workers and the increase in inequality. The volume presents a wide range of views on various aspects of the impact of technological progress on employment, inequality and society.

Who is right? Are we just a few more advances in computing power away from a world of abundance and leisure, or is a dystopia of concentrated wealth amid widespread impoverishment? As a group, economists tend to have a positive view of technological progress, as highlighted by Betsey Stevenson’s chapter “Artificial Intelligence, Income, Employment and Meaning”. Over the long run, technological progress has led to higher incomes and fewer hours worked (allowing more time for leisure). But most discussions tend to focus on the short-run disruption – those neg-

actively affected by such technological advance.

The impact on employment is taken up more explicitly in the chapter “Artificial Intelligence, Automation, and Work” by Daron Acemoglu and Pascual Restrepo. They set out a model in which there are displacement effects and countervailing forces. Displacement effects are straightforward – technological advances lead to a reduction in the number of workers needed to do a task. The countervailing effects lean against the displacement effect. There are three main effects to consider: i) a productivity effect which increases the demand for non-automated tasks; ii) a capital accumulation effect which increases the demand for labour; and iii) a creation of new tasks effect – technological progress allows the production of new goods and services that were hitherto not possible nor even imagined. They usefully point out that the history of automation suggests that the third or “reinstatement effect” is quite powerful.

The relatively benign view of technological progress is echoed in the chapter by Phillipe Aghion, Benjamin Jones and Charles Jones “Artificial Intelligence and Economic Growth”. Setting out a simple growth model that incorporates Baumol’s cost effect and AI in the production function, they show that a balanced growth path can be achieved. That is, even though automation means faster productivity growth in the automated sector, this relative performance to the non-automated sector means that the automated sector could end up being a smaller share of the economy (due to more rapidly falling prices). In fact, long-run growth is determined by the sectors that are essential but

hard to improve with technology.

James Bessen takes a complementary approach in “Artificial Intelligence and Jobs: the Role of Demand”. Too often, pessimists focus on the income effects of technological progress and ignore the demand effects. Turning to historical evidence, he shows that the benefits from declines in prices due to higher productivity can far outweigh the negative effect on income. Using examples from the cotton, steel and automobile sectors, he shows that the decline in prices led to enormous increases in demand for those goods. AI-induced technological progress could be no different, and so we should not discount the ability of this sector to also create large demand effects.

Austan Goolsbee also takes a positive view of the impact of technological change on the labour market in “Public Policy in an AI Economy”. One of the key concerns of the pessimists is that the speed of adoption of AI may simply be faster than previous periods of technological advance, and as such, the displacement effects will be hard to offset. Using data from the Jobs Opening and Labor Turnover Survey (JOLTS), Goolsbee shows that one must put such potential job losses in context. If all 3.5 million jobs driving trucks, buses and cars were automated over the next 15 years, that would entail 19 000 job losses per month. This compares to average monthly job creation in the United States in 2017 of 5.3 million jobs (and 5.1 million separations). It seems the impact, from a macroeconomy point of view, will be less dramatic than many conceive.

Jason Furman, in his chapter “Should We Be Reassured If Automation in the Future Looks Like Automation in the Past?”,

also tackles the issue of labour market disruption, but with a focus on income inequality. On this issue, there is more room to be concerned. Both Goolsbee and Furman note that one solution to mitigate the impact on workers is a Universal Basic Income. While attractive on first glance, both raise concerns that will likely impede any immediate adoption. That said, the ongoing COVID-19 pandemic moves this issue to the fore as to how best to support incomes in a digital, post-pandemic world.

Jeffery Sachs takes a less optimistic view in his chapter “R&D, Structural Transformation, and the Distribution of Income”. He notes that the decline in the labour share of value added in the goods sector, from more than 60 per cent to just below 50 per cent, is evidence of how automation can affect the distribution of income. As AI-based technologies are adopted, the same phenomenon may appear for many medium-skilled workers in other sectors of the economy, with the gains accruing to the owners of capital. As such, one could expect income inequality to worsen. While Sachs provides interesting qualitative results, the quantitative impact remains to be done.

The theme of inequality is picked up more substantively in Anton Korinek and Joseph Stiglitz’s chapter “Artificial Intelligence and Its Implications for Income Distribution and Unemployment”. They posit that while there are concerns about labour substitution, the biggest issue will be one of income distribution. Technological change leads to increased inequality through two channels. The first channel is that technological change creates rents for the innovator at the expense of consumers. The sec-

ond channel is that AI may reduce wages for the types of workers who are being displaced to the benefit of entrepreneurs. To rectify these outcomes, they propose several policies – namely taxes on the rents and robust anti-trust policies. At the same time, workers that are negatively affected by automation can be compensated, either in the form of wage subsidies or earned income tax credits. Higher wages for public sector workers would also help lift wages for low-income earners and public investment could help to ensure higher aggregate demand.

Building on the overall pessimistic view of the impact of AI, the authors also consider the case of human enhancement and independent artificial intelligence development (that is, machines that make even better machines). Not surprisingly, both outcomes lead to even greater inequality, with the latter case even ending in some proportion of the population being unable to feed itself. While this is an interesting thought-experiment, its place in a practical volume such as this one is somewhat misplaced.

The section is rounded out by Tyler Cowen’s chapter “Neglected Open Questions in the Economics of Artificial Intelligence”. There are three areas of focus. First, he asks how consumer surplus will be divided. If the costs of the AI-enabled outputs are declining (as is typically the case for software-intensive goods), then it bodes well in terms of consumer surplus and displacement effects. This is because the benefits can be widely spread while the impact of the workers displaced in the production of the good will be limited. A second neglected issue are the international ef-

fects. These include how wage differentials will evolve in a world of even more pervasive AI-enabled outsourcing and whether it will be possible for developing countries to industrialize in the same manner as some emerging market economies have done in the past. Lastly, Cowen asks how political economy considerations will assist (or not) the process by which income can be redistributed effectively, e.g. to caring for elderly persons. Needless to say, much research remains to be done to address these and many other questions.

## Machine Learning and Regulation

This section moves the discussion to how AI might affect firms' organizational structure, privacy issues, and commensurately, the implications for regulation of firms.

Hal Varian's chapter "Artificial Intelligence, Economics and Industrial Organization" provides a wide-ranging overview of how the adoption of AI will affect businesses' organizational structure. The chapter begins with a summary of what machine learning can do but adds little new given the previous chapters. The more interesting contribution comes in the form of how firms themselves may change. For instance, it is not immediately obvious if ML will increase or decrease the minimum efficient scale for a firm. Likewise, price discrimination can be more easily implemented with the use of ML and big data, but to what extent firms will aim for perfect price discrimination is unknown. Varian also raises some key concerns, such as collusion, security and privacy, which are tackled more comprehensively in the rest of the section.

While much of the discussion on the impact of AI on the economy is focused on economic issues, it is privacy that often receives the most attention by the wider public. Firms' use of ML to make better predictions and affect consumer behaviour requires large and detailed data on consumers. How these data are managed and used is often "front-page" news. Two chapters make very useful contributions on this front. The chapter "Privacy, Algorithms, and Artificial Intelligence" by Catherine Tucker outlines three key areas of focus: data persistence, data repurposing and data spillovers. Data persistence is a key attribute of the current environment. Data created through transactions, unlike in previous times, are very likely to persist. This creates a time-consistency problem. Data that a person may have felt comfortable giving when they were younger may not necessarily be that which their older self may find acceptable. While there is evidence that some of the biggest players in the ML space do not need long data histories to do their work, some forms of data may be very persistent. For example, genetic data can be very long lived (a lifetime or even beyond) and so how it is used and controlled is of considerable import.

The second issue is data repurposing. Data collected for one purpose may end up being used in a completely different context, often without the knowledge of the consumer. This lack of knowledge of use can be damaging to consumers. A third issue is that data spillovers are a natural outcome of ML algorithms themselves. The most concerning of these spillovers is the occurrence of algorithmic bias or discrimination. Recent high-profile cases have

shown that ML algorithms can introduce or reinforce existing biases if left unattended. For example, Amazon stopped an ML algorithm used for recruitment as it was seen to be biased against women. This reinforces the need for firms to use their data in an ethical manner.

The chapter “Artificial Intelligence and Consumer Privacy” by Ginger Zhe Jin highlights some of the new risks associated with the implementation of ML and big data in the consumer context. At the heart of these risks is that the firm may promise to respect data privacy *ex ante*, but renege on the promise *ex post*. Moreover, it is very hard for the consumer to even know if the promise of data privacy is being respected. High-profile breach cases, such as Target and Equifax, highlight the risks to both consumers and firms if they fail to keep their data secure. Firms may lose the trust of their customers, and customers may become the targets of misuse, ranging from fraud, identity theft, and even blackmail or extortion. Even if data are kept secure, Jin notes that data may not be restricted to their intended use, potentially harming the customer.

To reduce these risks, Jin points to two sources of mitigation: consumer attitudes and supply-side actions. Consumer attitudes are not a panacea. While many consumers profess concerns about privacy, in practice they are less strict in how they control their data. While this seems a paradox, it could be the case that consumers are willing to take the risk of giving away their data given the benefits they might receive from firms knowing them well. The more likely solution lies in supply-side actions. Firms actions have been mixed.

While many firms fear the market and reputational consequences of data breaches and invest in data security accordingly, the average firm suffers little material consequence when a breach occurs. Consequently, it will be the responsibility of the government to appropriately regulate and enforce data privacy and appropriate use. On this front, however, there is much to do. In the United States, for example, there is a patchwork of regulation and federal law in which firms and consumers operate. Shoring up this system can be done in many ways – safety regulation, consumer notice and disclosure and self-regulation – but each will need to be mindful of not thwarting the innovation that ultimately benefits consumers.

The question of who should be punished if AI goes astray, and the implications for innovation, is tackled in the contribution by Alberto Galasso and Hong Luo, “Punishing Robots: Issues to the Economics of Tort Liability and Innovation in Artificial Intelligence”. They present a simple model of the impact of liability risk on the incentives to innovate. The bottom-line is that liability risk does not necessarily chill innovation – rather, there is a complex, and often ambiguous relationship that depends on the expected payoffs of innovation relative to its liability risk profile. They then go on to enumerate some of the key liability issues as they relate to AI technology. Assigning liability to AI that goes awry is not so straightforward, and crafting a suitable legal framework that does not inhibit innovation remains an open question.

The last chapter in the section addresses the international dimensions of AI, an oft neglected subject. Avi Goldfarb and Daniel

Trefler, in “Artificial Intelligence and International Trade” focus on some elements that characterize AI – the benefits that come from economies of scope and scale, and knowledge externalities. As such, trade policies need to take account of these features, being mindful that some policies that are aimed at consumers (such as privacy policies, data localization) can end up as disguised trade polices.

## **Machine Learning and Economics**

The last section of the book focuses on the implications of ML on the discipline of economics. The first contribution by Susan Athey, “The Impact of Machine Learning on Economics” highlights the many ways in which machine learning can enhance econometric analysis. By leveraging big data and its inherently iterative approach, ML has the potential to improve the forecasting performance of key economic variables, and in doing so, allowing for better policy action. It will also likely allow for the investigation of economic questions that were not feasible in the past. In this context, some more concrete examples would be helpful along with the link to what it might entail for policy. Athey also correctly notes the current limitations of ML with respect to causal inference. While much progress is being made in improving the “explainability” of ML algorithms, there is still much work to be done before policymakers will be at ease with ML-based results.

The impact of ML on economics will also depend on the availability of data. In “Artificial Intelligence, Labor, Productivity, and the Need for Firm-Level Data”,

Manav Raj and Robert Seamans highlight the need for more and better data at the firm level if we are to better understand how AI is going to affect the economy. While there is some progress on this front, large data gaps remain. They offer some solutions, including a census of robots and surveys at the firm level. Unfortunately, for researchers, much firm-level data are proprietary, and will likely remain inaccessible in the near-term. In this sense, deeper collaboration between researchers and the private sector could be pursued.

The last two chapters look at the implications of AI/ML for market design and behavioural economics. In both cases, the insight is simple. ML provides the opportunity to better understand the economic phenomena at hand to inform decision-making. In the case of market design, Paul Milgrom and Steven Tadelis in “How Artificial Intelligence and Machine Learning Can Impact Market Design” showcase how ML was used to consider the implications of re-allocating frequency bandwidth in the US market. Simply, without ML, it would have been almost impossible to consider the set of options at hand in a systematic fashion. Colin Camerer, in “Artificial Intelligence and Behavioural Economics”, shows how ML could be leveraged to better model behavioural choices. This is because ML allows the researcher to consider a wider range of factors that could affect decision making than more standard models.

## Conclusion

The volume provides a comprehensive view of the economics of artificial intelligence. The volume is for the most part accessible, as most of the contributions can be understood with a basic level of economics. However, from time to time, some of the chapters present models that would be beyond the comprehension of many intended readers.

A wide range of topics are covered in the book, with an appropriate focus on why AI could lead to (or not) a pickup in productivity growth and the expected impacts on the labour market. In this respect, the volume successfully presents both sides of the debate in a constructive manner. However, it might have been useful to have a) some discussion of what happens if the anticipated productivity gains do not occur and b) a summary chapter on the issue of whether AI boosts trend productivity

growth in order to form an overall view on the subject.

There are two issues that only received cursory attention. The issue of the impact of AI on competition could be better explored. The rise of superstar firms, driven by AI, has raised many anti-trust issues and increases in industry concentration is seen as one of the main contributors to ongoing inequality. Relatedly, some discussion of who owns and controls data would have been insightful. That said, for an informed reader, this volume provides a great primer on the economics of artificial intelligence.

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