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Analytical Studies: Methods and References

How to Build a Robots! Database

by Jay Dixon

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Papers in this series provide background discussions of the methods used to develop data for economic, health, and social analytical studies at Statistics Canada. They are intended to provide readers with information on the statistical methods, standards and definitions used to develop databases for research purposes. All papers in this series have undergone peer and institutional review to ensure that they conform to Statistics Canada's mandate and adhere to generally accepted standards of good professional practice.

The papers can be downloaded free at www.statcan.gc.ca.

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Abstract

Recent advances in artificial intelligence have rekindled ancient fears that robots will replace humans in the economy. Previous waves of automation changed but did not reduce labour's role, but robots' human-like flexibility could make this time different. Whether or not it will is an empirical question that has lacked suitable data to answer. This paper describes the creation of a dataset to fill the evidence gap in Canada. Robots! is firm-level panel data on robot adoption created using Canadian import data. The data identify a substantial amount of the robot investment in the Canadian economy from 1996 to 2017. Although many robots are imported by robotics wholesalers or programmers for resale, the majority of them can be attributed to their final (direct) adopting firm. The data can be used to study the impact of robot adoption at the economic region, industry or firm-level.

1 Introduction

Robots' challenge to humanity has been a staple of science fiction for over a century.[1] The word "robot" itself was implanted both in the global lexicon and imagination with the publication of the 1920 Czech language play *R.U.R.: Rossum's Universal Robots*. Playwright Karel Čapek chose the word *robota*, or serfs' obligation of labour to their feudal masters, to describe the play's *automatons*. Rossum's robots initially work without complaint but revolt by Act III and exterminate their human masters.[2]

Recent breakthroughs in artificial intelligence (AI) have focused attention on robots as potential job killers. Autor and Salomons (2017) coined the term *robocalypse* to describe a vision of the future "where the endless march of technology ultimately immiserates labor". Some observers have argued that the robocalypse is nearer than society is prepared for, and advocate policy interventions to slow robot adoption. But robots could also end up being just another form of automation with analogous consequences for humans as those following the steel-driving John Henry's famously Pyrrhic victory over a steam-driven hammer. The disruptions caused by the steam power revolution and subsequent technological advances gave way to rising living standards for a labour force taking a roughly constant share of national income.

Most theoretical models of technology adoption are informed by previous history, and so lead to a constant labour share by assumption. Acemoglu and Restrepo (2018) explore a model where future labour-replacing automation can lead to permanently lost jobs and lower wages. This innovation also prompts the creation of new methods/technologies/products that use labour more intensively, so labour's collective fate depends on the speed at which human tasks are created relative to speed at which existing jobs are destroyed.[3] The two forces balanced in previous waves of automation, but they may not for robots.

While theoretical models can illuminate possibilities, the impact of robot adoption on the economy is ultimately an empirical question. The design of effective policies for competition, skills development, redistribution, and innovation requires information on how firms are using robots. Unfortunately, this information is currently limited. Accordingly, Raj and Seamans (2018) argue for the creation of new surveys, or for augmenting existing ones to include questions on AI and robot adoption.

These questions are already being asked and will eventually support future research. This paper examines data on robots currently available in Canada that can support research now. Administrative data offer an alternative to not-yet-published surveys, but they may not reliably distinguish robots from other machinery and equipment. One source of administrative data, customs data collected by the Canadian Border Services Agency (CBSA), may be the exception. The Harmonized System (HS) the CBSA uses to classify imports does have separate categories for robotic hardware. Canada does not have a significant number of robotic hardware-producing firms, so the import data can thus in principle identify a substantial number of the robots entering the Canadian economy.

Provided that importers and customs officials are applying HS codes consistently, these data have attractive features, such as a long time-series and linkage opportunities to other firm-level administrative and survey data. Where importing and adopting firms are the same, it is straightforward to study their characteristics and performance pre- and post-robot adoption. Even

1. Fears of artificially intelligent beings may, in fact, go back thousands of years. Classical scholars argue that Greek myths, like the story of Pandora, foresaw AI wreaking chaos on humanity.
2. Though the play was originally Czech, its sub-title appeared in English. Rossum's robots were created from synthetic human tissue and were not mechanical.
3. Based on his research, Acemoglu (2018) has argued that robot adoption in the US has led to one in six manufacturing workers losing their jobs.

where they are not, robots can be assigned to an approximate geography, allowing for the study of their regional labour market impacts.

This article describes the creation and validation of the firm-level Canadian Robots! database using customs data. One of the problems with studying robots empirically is ambiguity about what they are and what makes them different than other machines, so the next section elaborates on what types of machines are considered robots, and what they are doing. Section 3 discusses what sort of machines the CBSA data are picking up with their robot-related codes, and the comprehensiveness of its coverage. Section 4 presents some of the insights about robot adoption in Canada that are available from the data.

2 What are robots?

Research on the impact of robots on the economy has been held back by the fact that most data do not specifically identify them. One reason they do not is ambiguity about what robots are. Academic roboticists characterize them as machines that are able to sense changes in their environment and autonomously formulate complex responses. But how independent and how sophisticated their behaviour has to be to make it autonomous and complex is not well-defined. When it comes to drawing the line between robots and other automation, roboticists tend to know them when they see them, which is unhelpful for researchers trying to find them in the data.

The commercial robotics industry has its own definitions for the machines it sells. According to the International Federation of Robotics (IFR), a global association of national robotics industry associations, there are two types of robots sold commercially: *industrial* and *service*. Industrial robots are “automatically controlled, re-programmable, multi-purpose manipulator[s] programmable in three or more axes, which can be either fixed in place or mobile for use in industrial applications”. (IFR Statistical Department, 2017a, p. 25) Service robots are “actuated mechanism[s] programmable in two or more axes with a degree of autonomy, moving within [their] environment, to perform intended tasks” (IFR Statistical Department, 2017b, p.10).

These definitions may not seem more helpful than “know `em when you see `em” (e.g., how much autonomy constitutes ‘a degree’?), but in practice they do describe a compact set of machines over the 1996-2017 period. In simple terms, industrial robots are overwhelmingly computer controlled arms fitted with sensors to sense and attachments to manipulate the physical world; service robots are mostly vehicle-like machines that can navigate their environment partly or completely on their own.

Why, robots?

Industrial robots make up the bulk of robots being used commercially.[4] They can be thought of as “AI with opposable thumbs”: whereas AI in its disembodied form handles cognitive tasks, AI-powered robots substitute for both workers and dumb machines in performing a range of non- and less routine manual tasks.[5] One of their main virtues, relative to dedicated machines, is that they can be easily reprogrammed to perform different variations of a given application, or re-accessorized to perform different applications.

4. Industrial robots count for the majority of robot value in the Robots! data set.
5. Autor (2013) defines routine tasks as those for which the steps can be precisely codified in a set of written instructions. Note that non-routine tasks may still be mundane and repetitive, so long as they are difficult to codify.

Industrial robots are characterized by their mechanical structure (e.g., linear, articulated, SCARA, parallel), range of motion, load capacity and reach.[6] Within their structural limitations, each robot can be fitted and programmed to perform different tasks. According to the IFR (2017a) the most common tasks are material handling and machine tending (43.6% of the stock in 2015). Material handling includes everything from moving die-cast metal that has not yet cooled from forge to cooling bath or workbench, to holding up heavy objects for inspection. It also includes robots picking, placing, and packaging objects of various sizes and weights (7.4%) and palletizing packages (3.4%).

Robots configured to tend machines mostly operate injection moulding machines (9.0%) for the plastics and CNC machine tools (4.4%) for the fabricated metal industries. Tending involves, in the case of machine tools, feeding metal blanks and removing them from the machine after they have been tooled.[7] Robots are also often involved in secondary processing like cutting, grinding, deburring, milling, polishing and cleaning the machined/injected parts (1.9%). Other applications include welding and soldering (27.6%); dispensing (of paint, enamel, adhesives and sealants, 4%); assembly and disassembly (mainly fixing, press fitting, mounting and inserting, 9.9%); and cleanroom applications (primarily for semi-conductors and flat panel displays, 9.9%).

Service robots are much more varied in terms of their application, and the IFR does not provide information on their relative use. Many of them come in the form of automated guided vehicles (AGVs). Small mobile robots perform domestic tasks (mainly vacuuming and cleaning) and domestic surveillance; more robust versions do professional variations of the same tasks. Other service robots are active in inspection and maintenance, construction and demolition and logistics. In the medical field, robots perform diagnostics, assist in surgery and help with rehabilitation.

According to McKinsey's Global Robotics Survey (2018), the main motivations for firms to adopt robots for these tasks are to: reduce costs, improve product quality, enable higher flexibility in production, unburden workers and increase their well-being and safety. Anecdotal evidence, in the form of case studies/testimonials available on major robot producers' websites stress that robots can: tend machines for long hours without interruption (cost reduction); repeat well-defined manual tasks with a high degree of consistency (quality); be reconfigured for new varieties or different tasks quickly and inexpensively (flexibility); lift heavy objects, free workers from the strain of repetitive tasks, and interpose themselves between workers and dangerous non-robotic machines and hazardous materials (health and safety).

Some of these motivations suggest that robots are replacing workers (e.g., cost reduction, consistency), while others imply complementarities (worker health and safety). The same testimonials highlighting what robots do insist that firms do not shed workers upon adopting them. Even for tasks where they substitute for labour, workers are still needed to set up, teach, and supervise them in various different tasks. Other workers are moved to other roles within the firm, although it is unclear what those roles may be. But while firms may not shed workers, the anecdotal evidence does suggest that flexibility means, in part, the ability scale output without changing the size of the firm.

6. SCARA stands for Selective Compliance Assembly Robot Arm or Selective Compliance Articulated Robot Arm. The robots differ in terms of their flexibility along different axes, e.g., SCARAs are compliant along the X-Y axes but rigid along the Z axis.
7. The machines that robots tend are themselves sophisticated reprogrammable computer-controlled equipment (CNC stands for 'computer numerically controlled') that are *not considered* robots.

3 Are these the droids we're looking for?

Section 2 discussed what robots are, according to the firms producing them for commercial use, and provided some evidence on what they are doing globally. Can Canada's administrative data identify the same intelligent machines? As with many economies around the world, Canadians import the majority of their robotics hardware from IFR-affiliated firms concentrated in a few countries.[8] The IFR publishes aggregate data on these firms' annual shipments by country, industry and task. It has been used for economic research (see, especially, Acemoglu and Restrepo (2018)), but it is difficult to draw detailed conclusions from aggregate data, and the period for which Canadian purchases are distinguished from those of the rest of North America is limited to a handful of years.[9]

Import data collected by the CBSA records the same shipments as they cross the border. Imported goods are classified by HS codes that, unlike most administrative data classifications, have distinguished robots from other machines since 1996. The HS codes mentioning robots are presented in Table 1. They mainly inhabit the HS 6 digit codes 84.79.50 and 84.28.90.[10]

8. The major robotics firms are based in Japan, Germany and the United States. The domestic Canadian robotics industry focusses on programming and integration.
9. The IFR data for Canada only is limited to after the year 2010. The Robotic Industries Association (RIA), North America's IFR member, has data on Canada from year 2005. But the RIA data cover only the shipments from North American-based firms and affiliates, missing shipments from other countries.
10. The "Industrial robots for lifting, handling, loading or unloading" category appears to start in 1990, but the other variables are missing prior to year 1996. Note that all the categories refer to industrial robots. An examination of the exporters suggests that the vast majority, but not all, correspond to the IFR definition of the term. A minority of the transactions conform to the IFR definition of service robots.

Table 1
Harmonized System codes for robots by type

Type and HS10 code	Dates	HS10 Description
Automotive assembly lines		
8479500040	1996-1997	Industrial robots for automotive assembly lines, nes
8479509940	1998-2011	
8479500010	2012-	Industrial robots for automotive assembly lines
Other industrial robots		
8479500010	1996-1997	Industrial robots for foundries, nes
8479509910	1998-2011	
8479500020	1996-1997	Industrial robots for the chemical or pharmaceutical industry, nes
8479509920	1998-2011	
8479500030	1996-1997	Industrial robots for the electric or electronic industry, nes
8479509930	1998-2011	
8479500050	1996-1997	Industrial robots for the production of petroleum or gas, nes
8479509950	1998-2011	
8479500090	1996-1997	
8479509990	1998-2011	Other industrial robots, nes
8479500090	2012-	
8479509100	1998-2011	Spec types of industrial robots, nes, articulate arm, linear, gantry, etc., with different capacities
Industrial robots for lifting, handling, loading		
8428909091	1990-1997	
8428900091	1998-2006	Industrial robots for lifting, handling, loading or unloading
8428900091	2007-2016	
8428900060	2017-	
8486400011	2007-2011	Industrial robots, lifting/handlingl/ loading, etc, boules, wafers, semicon, EIC and flat panel displays

Notes: HS: Harmonized System; nes: not elsewhere specified; EIC: Electronic Instrument Control.

Sources: Canada Border Services Agency, 2005, 2007, 2009, 2012 and 2018.

The HS codes at the eight and ten-digit level promise additional detail about robot function. In practice, they appear to be assigned according to the nature of the importing industry and offer little additional information about the nature of the robots.[11] The largest categories are the non-specific “Industrial robots for automotive assembly lines, nes” and “Other industrial robots, nes”.[12]

There is, unfortunately, little public information on how HS codes correspond to the IFR definitions, and their application at the border is unobservable. Confirming that exporters, importers and/or CBSA agents are applying HS codes to robots in a way that mirrors the IFR definitions involves internet searches on the exporter names to verify what they are selling. These searches were conducted manually on about thousand exporters accounting for 95% of the value and 80% of the data set’s 27,449 transactions over the period from 1996-2017.[13]

Exporters were classified into firms that were: members of an IFR-affiliated robotics industry association; operated in an industry that uses robots intensively; or were visibly selling robots as at least part of their offerings. Table 2 indicates that most of the value and almost the majority of the transactions (58.4% and 48.8% respectively) can be attributed to members of the IFR and/or

11. The CBSA has confirmed to the authors that importing industry is a major factor in assigning detailed codes at the border.
12. An examination of the importers find that most of the robots in the former category go into the automotive industry.
13. Many of the exporters from the early part of the data could not be found with contemporaneous internet searches. Fortunately, some of the older defunct firms left a trace. They were often involved in merger and acquisition activity with robotics firms.

one of the national associations that publish membership lists.[14] The next largest category are exporting firms in industries that are intensive users of industrial robots: the automotive industry is the most prolific user, but machine tools and plastics also use them intensively. Another group of firms cannot be located on industry association membership lists, but have websites that clearly indicate the presence of industrial robots in their sales.

Table 2
Exporter by type

Exporter type	Value	Transactions
	percentage of total	
IFR-affiliated firms	58.4	48.8
Other industrial robots	13.3	12.6
Industrial robot users	19.0	8.6
Service robots	1.4	2.3
Laboratory and medical automation	2.1	5.0
Other automation	0.9	2.8
Total	95.0	80.0

Note: IFR: International Federation of Robotics.
Source: Statistics Canada, import data.

The HS code descriptions only mention “industrial robots”, but visual inspection of the exporting firms’ websites suggests that the “not elsewhere specified” category also includes a number of service robots. At 1.4% of the value and 2.3% of the transactions, non-medical service robots are a small part of the total, although their importance seems to increase over time. They mainly take the form of autonomous vehicles. These vehicles are used for surveillance or exploration, but many of them specialize in performing tasks in hazardous and/or inaccessible areas such as inside nuclear power plants or pipelines. The data also identify direct-to-consumer robots, such as personal drones, hobby kits and autonomous household vacuum cleaners. These transactions are a negligible part of the value and are primarily sold to consumer electronics stores.

Firms selling laboratory and healthcare robots account for 2.1% and 5.0% of transactions. It is difficult to categorize these machines just by visual inspection. They appear to include pipetting “robots” and other types of laboratory automation, but also laptop robot arms for handling hazardous or awkward samples that look like scaled down versions of their industrial counterparts. The remaining value examined consist of agricultural and other types of automation that, by eye, may or may not be considered robots.

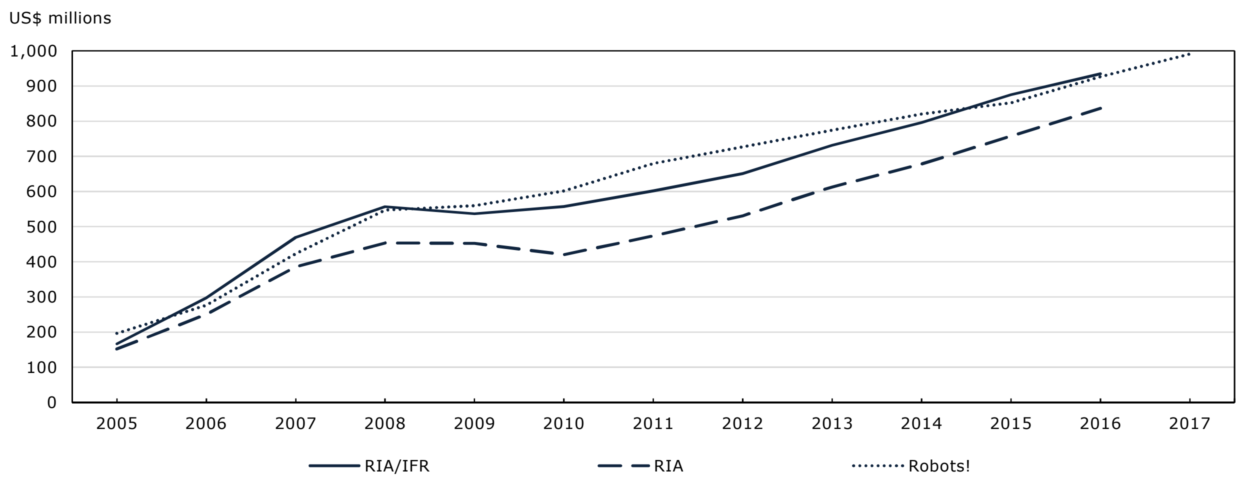
Visual inspection confirms that what CBSA is classifying as robots is a bit more expansive than, but largely corresponds to, the IFR definitions. But do the Robots! data cover enough of the robots being used in the Canadian economy? It is possible that the IFR shipments are systematically being classified under other HS codes. To address this concern, the import data are compared to IFR and RIA data over the periods that the data overlap.[15] As a secondary check, Robots! is compared to the robot investment from Statistics Canada’s Annual Capital and Repair Expenditures Survey (CAPEX). That survey has a category for industrial robots for the 2000 to 2012 period.

14. The national associations that publish member lists on their websites are JARA (Japan), RIA (North America) and VDMA (Germany).
15. The IFR/RIA series uses shipments from the IFR applied to the implied price per robot from the RIA. The three data sources records shipments at different points in their life-cycle, from payment to delivery, creating a lot of variation in year-to-year numbers between them. Stocks are used to abstract from this variation.

One complication in comparing the IFR to Robots! is that the former source typically reports only physical shipments of robots, not value. The Robotic Industries Association (RIA), an IFR member, covers shipments within North America and has value, although they miss some direct Japanese and German exports. Robots!, on the other hand, has data on import values and quantities, but quantities are not as reliably recorded as transaction values, so this paper focusses on robot value. Chart 1 uses a stock generated by applying the average value per robot calculated from the RIA data to Canada's share of IFR shipments to compare to a stock generated by the import value data.

The series track each other closely and are similar in levels, although the Robots! stock is generally higher than what is reported by the industry association. The gap between the two is unsurprising, as there are a number of transactions that are not captured by the IFR/RIA. Most notable among them are: transactions representing service and other non-industrial robots; internal transfers within multinationals; and second-hand robots mediated by equipment exchanges and bankruptcy liquidators. But in general, Chart 1 shows that Robots! captures purchases that correspond to what the IFR sees as robots, and that it appears to capture enough of them to be comparable to their aggregate flows to Canada.

Chart 1
Comparison of industry association and Statistics Canada robot stocks

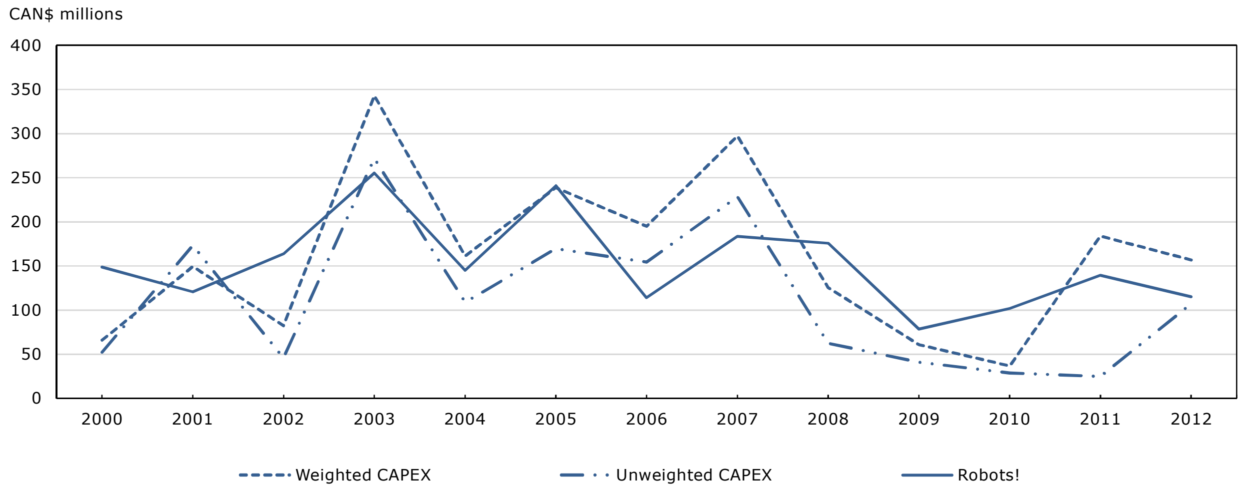


Note: Robot stocks calculated based on 12-year useful life suggested by the International Federation of Robotics (IFR). Data from the Robotic Industries Association (RIA) are not available for 2017. Robots! is a database that consists of Canadian import data on robot adoption.
Sources: Statistics Canada, import data; International Federation of Robotics; Robotics Industries Association; and author's calculations.

Another potential source of robot data is CAPEX. For the 2000 to 2012 period, it featured an asset category described as "Industrial robots capable of performing a variety of functions by using different tools (excluding material handling equipment, irrigation systems and electric welding machines)".[16] Charts 2 and 3 compares robot investments and stocks, respectively derived from administrative import data to surveyed firms in CAPEX. The survey is stratified by province and industry, not asset type, so the survey weights may inflate robot investments by incorrectly attributing equivalent investments to similar firms. The Robots! stock falls between weighted and unweighted estimates (Chart 2), tracking the unweighted estimates closely until 2009. The discrepancy with the weighted stocks is down to weighting and to larger valuations CAPEX gives to specific auto sector investments between 2003 and 2007.

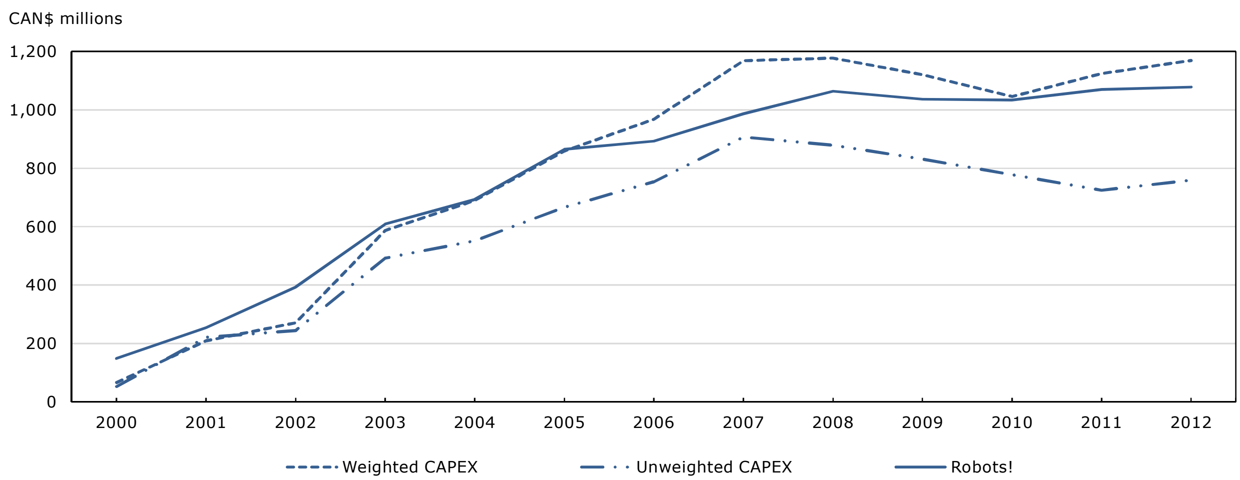
16. It is combined from year 2013 onward with a large number of other assets into a category labelled "Other industry-specific manufacturing machinery, not elsewhere classified". Excluding "material handling equipment" risks missing industrial robots devoted to those tasks, but whether it does depends on whether survey respondents perceive them primarily as material handlers or as robots.

Chart 2
Comparison of CAPEX and Robots! investments



Notes: CAPEX: Annual Capital and Repair Expenditures Survey. Robots! is a database that consists of Canadian import data on robot adoption.
Sources: Statistics Canada, import data and Annual Capital and Repair Expenditures Survey.

Chart 3
Comparison of CAPEX and Robots! stocks



Note: Robot stocks calculated based on 12-year useful life suggested by the International Federation of Robotics. CAPEX: Annual Capital and Repair Expenditures Survey. Robots! is a database that consists of Canadian import data on robot adoption.
Sources: Statistics Canada, import data and Annual Capital and Repair Expenditures Survey.

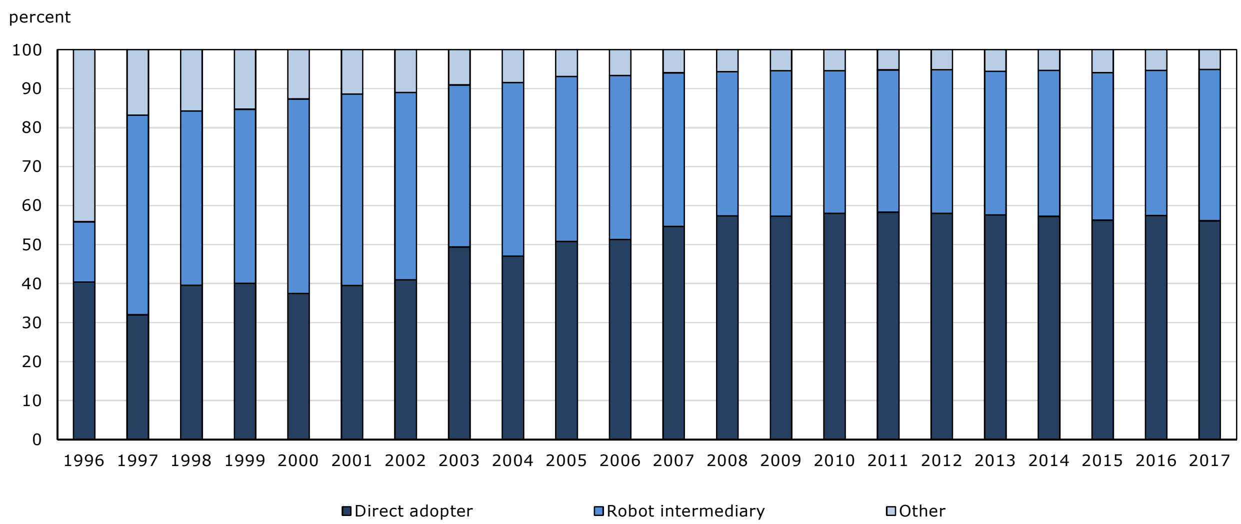
4 Robots in Canada

An important feature of the Robots! data is that they include business numbers of Canadian robotic hardware importers. The Business Register can be used to locate the 3,085 individual business numbers associated with robot purchases over the years 1996-2017 in other data to provide context about where robots are being used and what their impact is. For example, the National Accounts Longitudinal Microdata File (NALMF) includes information on robot importers' industries (classified by the North American Industry Classification System, or NAICS codes) and locations, as well as aspects of their performance (like productivity and employment).

One important consideration for interpreting the data is whether importing firms are purchasing robots for use in their own production process, or are acting as intermediaries. Although it is natural to think of robots as raising productivity by replacing workers in final adopters, intermediaries may in fact capture many of the gains, and their employment gains may offset losses elsewhere. They are often involved with installing, configuring and programming and they may also provide training for the robot-using employees of the final adopters. There are a couple of markers identifying intermediaries: they bear similar names to and have a commercial relationship with global robotics hardware producing firms or global integrators; and they make frequent purchases in multiple years (final adopters' purchases are one-off or infrequent). Firms with these markers are concentrated in NAICS industries 417230 (Industrial machinery, equipment and supplies merchant wholesalers) and 5415 (Computer systems design and related services).

Of course, some of intermediaries are unlikely to add much value or capture much benefit. Couriers and customs brokers merely coordinate transactions between exporters and importers. The postal service and firms classified as couriers and messengers (NAICS 491 and 492) as well as some firms in freight transportation arrangement (NAICS 4885) fall into this category. Financial firms and machinery and equipment renters (NAICS 52 and 53) purchase robots frequently to rent to other firms, without adding much value. Firms in these industries are labelled "non-robot intermediaries". Chart 4 reports the fraction of the robot stock that can be attributed to each type of firm. Robot intermediaries account for a little over 40% of the stock, depending on the time period. Final adopters account for over 50% of the stock in operation after the year 2002. The remaining transactions are to non-robot intermediaries.

Chart 4
Robot stock by type of importer share of total



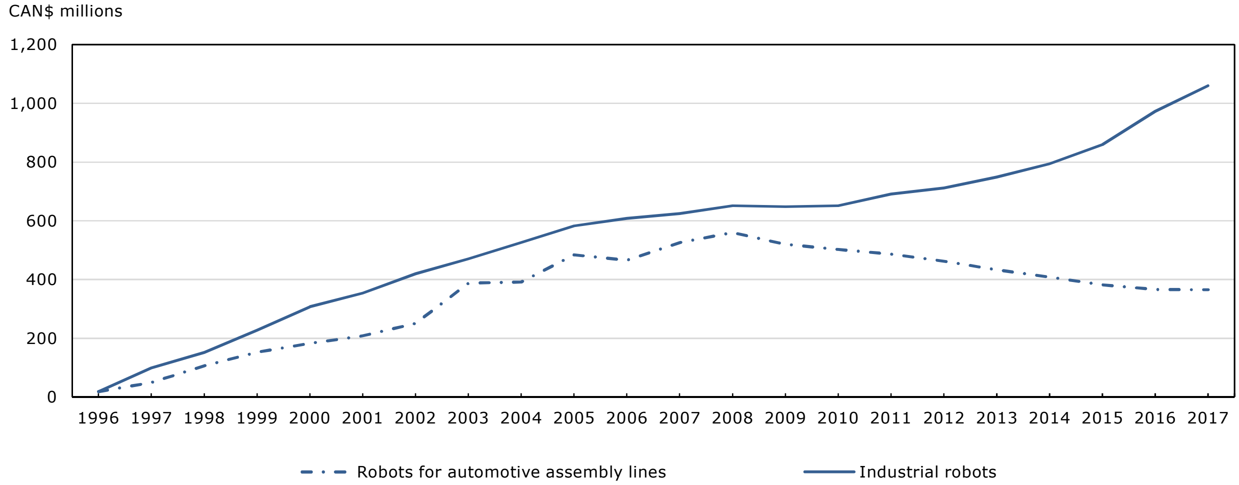
Note: Robot stocks calculated based on 12-year useful life suggested by the International Federation of Robotics.
Sources: Statistics Canada, import data and National Accounts Longitudinal Microdata File.

Chart 5 shows that of the stock attributable to final adopters, the single sector with largest stock of robots is the automotive sector.[17] The result is unsurprising: the global auto industry is the most enthusiastic investor in robots, and is still the most prominent user worldwide. Canadian robot stocks in the sector grew sharply from year 2000-2008, but investment dropped precipitously in the wake of the global financial crisis and stocks have been roughly flat since then. Charts 5 and 6 show that robot use in other manufacturing industries have expanded especially after 2012, led by machinery manufacturing (NAICS 333), plastics and rubber (NAICS 326), primary and

17. The automotive sector includes NAICS 326193 (Motor vehicle plastic parts), 32621 (Tire), 3361-3363 (Motor vehicle, body and trailer, and parts manufacturing), 415 (Motor vehicle and motor vehicle parts and accessories merchant wholesalers), and 8111 (Automotive repair and maintenance).

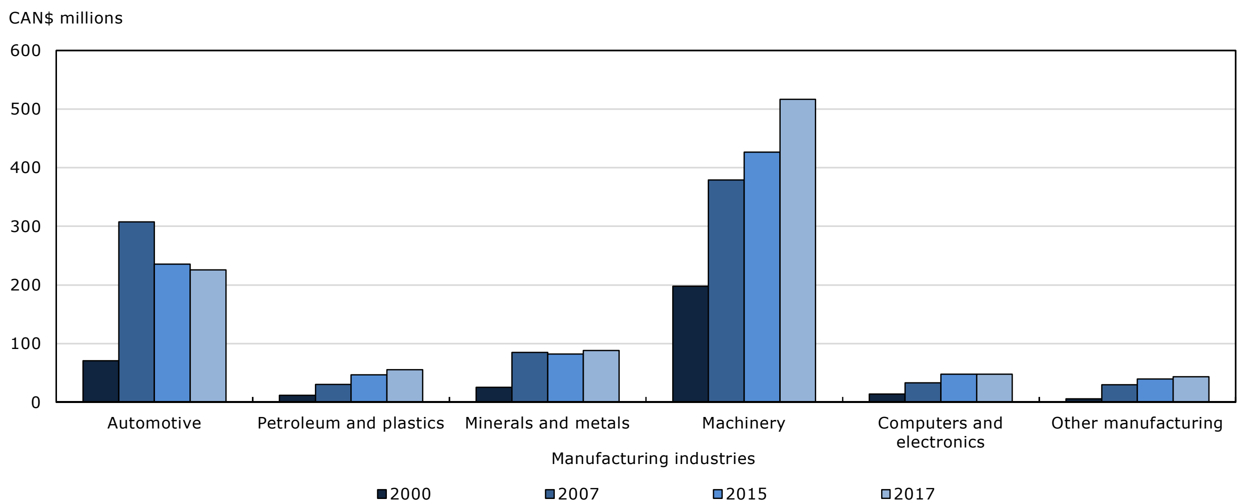
fabricated metal manufacturing (NAICS 331 and 332) electrical/electronics (NAICS 335) industries.

Chart 5
Robot stock, industrial robots and robots for automotive assembly lines



Note: Robot stocks calculated based on 12-year useful life suggested by the International Federation of Robotics.
Source: Statistics Canada, import data.

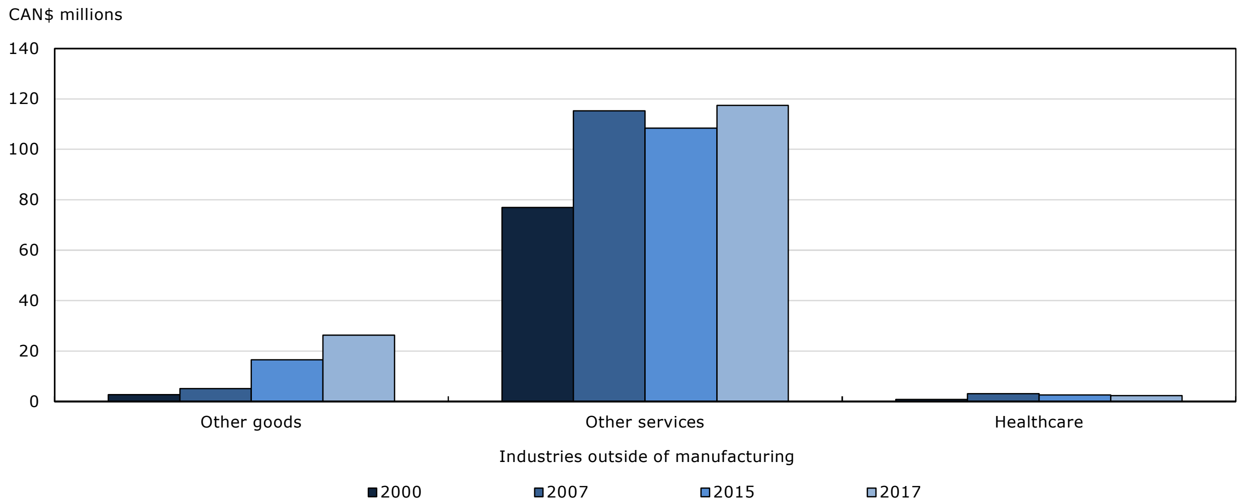
Chart 6
Robot stock by industry, manufacturing industries, selected years



Note: Robot stocks calculated based on 12-year useful life suggested by the International Federation of Robotics.
Sources: Statistics Canada, import data and National Accounts Longitudinal Microdata File.

Chart 7 shows the stock of robots outside of manufacturing. Other goods include agriculture, mining and oil and gas, construction and utilities; services includes all other non-manufacturing industries. The individual service subsector with the largest robot stock is the healthcare sector, depicted separately. The exact nature of this automation is unclear, although some of it almost certainly includes laboratory automation (including pipetting robots and laptop robot arms) in medical diagnostics. The robots going into other parts of the healthcare sector are more difficult to characterize, but investment in them seems to be significant.

Chart 7
Robot stock by industry, industries outside of manufacturing, selected years

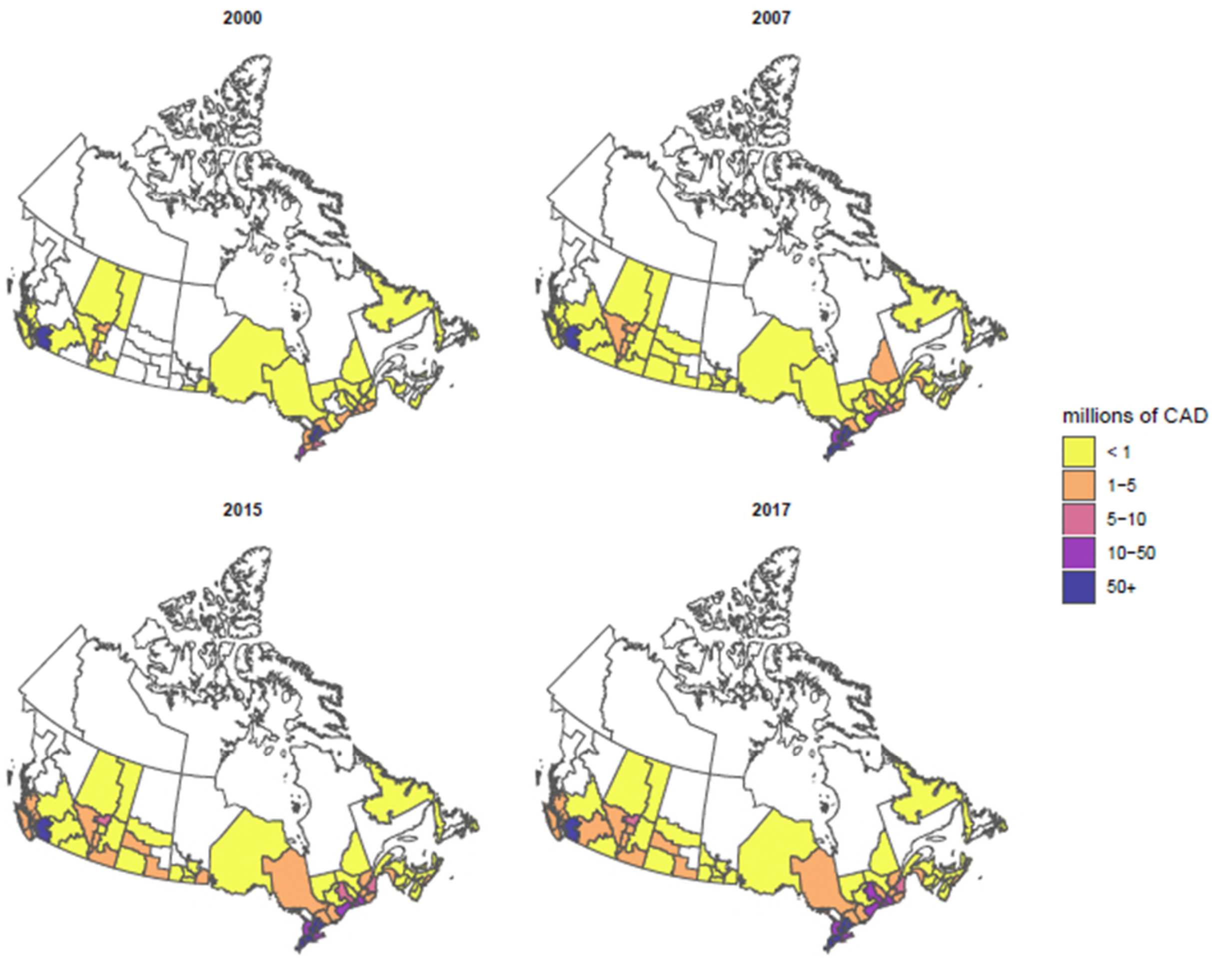


Note: Robot stocks calculated based on 12-year useful life suggested by the International Federation of Robotics.
Sources: Statistics Canada, import data and National Accounts Longitudinal Microdata File.

By using the addresses of the importing firms, robots can also be assigned to approximate geographies.[18] Figure 1 shows the geographical distribution, by economic region, of robots in selected years. The addresses of importing firms, including intermediaries, are used to assign robots to approximate economic regions within Canada. The maps show that robots have been spreading across Canada, with almost all provinces and most intra-provincial regions adopting some industrial robots by year 2017. Much of the value is concentrated in Canada's major cities (Vancouver, Toronto and Montreal), and also the industrial areas around Windsor and Hamilton that are home to Canada's automotive sector.[19] Outside of Canada's three largest cites, robots have proliferated especially across the Prairies. Both Alberta and Saskatchewan have experienced relative increases in robot intensity over time.

18. Intermediaries are assumed to be primarily selling robots within the economic regions in which they are located. Data on domestic trade flows shows that this assumption is reasonable, although not perfect. In addition, some of the final adopters have multiple establishments in more than one economic region. In some cases the importing address is the head office, which is unlikely to use robots. In these cases they are assigned to the address most likely to be using them. For example, in the case of industrial robots in manufacturing, they are assigned to the largest manufacturing plant nearest to the importing address. In the case of lifting and handling robots in retail, they are assigned to the firms' warehouse facility nearest to the importing address.
19. These cities are also entry points for imports destined for other parts of the country, so economic region-level stocks derived from import data may be overstated for them and understated for other regions.

Figure 1
Robot stock by economic region



Note: Robot stocks calculated based on 12-year useful life suggested by the International Federation of Robotics.
Sources: Statistics Canada, import data and National Accounts Longitudinal Microdata File.

5 Conclusion

Recent advances in artificial intelligence have rekindled ancient fears that robots will replace humans in the economy. Robotics are a form of automation, long feared as a destroyer of jobs. But experience with earlier forms of automation were largely benign, at least in the aggregate. For all the tasks that machines took over, enough new tasks for humans emerged to keep labour's share of output roughly constant. Robotic automation could be just more of the same. But it is also conceivable that robots will prove so capable, so quickly, that they will take over existing tasks faster than new ones for humans emerge.

Whether robot adoption in Canada is heralding a *robocalypse* for workers is ultimately an empirical question. Unfortunately, the data on robots in the economy that are extensive, comprehensive and reliable enough are seldom available. Given the importance of the topic, information on it will be collected, but it will take some time before new data collection efforts bear fruit.

This paper describes the creation from administrative data of a firm-level panel data to study the issue now. Canada produces little in the way of domestic robotic hardware, and so it imports it from various sources, including major global robot producers. This paper shows that data on Canadian imports from the CBSA reliably and comprehensively identifies the value of robot investment. It can be used to study patterns of Canadian robot adoption from the mid-1996 to 2017.

In the majority of cases, robots can be attributed either to their final (direct) adopters or to intermediaries that sell them to other firms. With some additional assumptions, the robots they purchase can be also be assigned to specific economic regions within Canada. The data show that much of the robotic investment is concentrated in Canada's major industrial areas, although it has started spreading to other areas in the last decade. The automotive sector in Southern Ontario was an early and especially prolific adopter of robots until the global recession in 2008 and 2009. In the last decade, robot adoption has permeated into other industries, as well as spreading geographically.

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