B Supplement to "What If? ...": Real-World Examples of Substitution and Substitution in the Macroeconomy

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This supplement to Bachmann et al. (2022) discusses in more detail the economic idea of substitution.[16] Section B.1 provides some historical real-world examples that demonstrate how firms do find ways to substitute in adversity (perhaps unexpectedly even for themselves). Section B.2 makes some additional general observations on substitution in the macroeconomy, in particular that a commonly held micro "engineering view" of substitution is too narrow and misses important mechanisms through which the macroeconomy would adapt to an import stop.

B.1 Real-World Examples of Substitution in Production

1. Rare Earth Embargo against Japan 2010. In 2010 China effectively implemented an export embargo on rare earths against Japan. Superficially, this resembled a textbook example of effective sanctions: China was virtually the sole supplier of rare earths, while these were an important input for Japanese industry.[17] As noted by Gholz and Hughes (2021), in the short run, Japanese firms reduced demand both at the intensive and extensive margin: firms that crucially needed rare earths in their input came up with ways to use raw material more effectively, thus pushing the technology frontier outwards. For example, glass manufacturing companies started recycling cerium polish, which requires the eponymous rare earth mineral. Other firms such as headphone manufacturers that previously bought rare earths due to its low cost - rather due to them being critical for the production process - substituted away completely. In the medium to long term, Japanese firms are working on technological innovations which too either reduce usage of rare earths or enable substitution with different materials. Reductions on the consumer side, such as post-consumption recycling, appear to play a lesser role due to practical difficulties. On the supply side, it took two years until alternative producers entered the market, even though investments for these projects had started long prior to the embargo. The Japanese government subsequently supported one of the firms via a long-term supply contract, which ensured its survival amidst price fluctuations in the years after the embargo subsided.

2. Shutdown of the Druzhba Pipeline due to Contamination. The Druzhba Pipeline is one of the main oil networks in Europe, connecting oil fields in the Russian Tatarstan region with Poland and Eastern Germany (northern branch) as well as Slovakia, the Czech Republic, and Hungary (southern branch). For Germany, the Druzhba pipeline transports around one third

[16] We are grateful to Vasco Carvalho, Basile Grassi, Camille Landais, Guido Lorenzoni and Lukasz Rachel for useful comments and to Marina Feliciano and Borui Niklas Zhu for excellent research assistance.

[17] Some authors argue that the embargo was not fully effective, see e.g. Johnston (2013). However, the embargo seems to have triggered some substitution by Japanese firms so it arguably must have been effective to some extent.

of total oil imports, and in particular supplies entire refineries in Eastern Germany. In 2019 it was discovered that oil pumped through Druzhba was contaminated with substances that damage petrochemical processing equipment through corrosion. As a result, pipeline operations were completely shut down for a few weeks.

The refineries that depend on Druzhba (in particular the Leuna and Schwedt refineries) quickly substituted its services with importing oil via ship to harbour terminals in Gdansk and Rostock, which enabled all refineries to continue operating, although not necessarily at normal capacity. In the case of an oil embargo as is under consideration now, the oil would have to come via ship, but not from Russia as in 2019 and it would need to be of a similar quality as the Russian blend. The 2019 experience thus provides some reason for optimism that German refineries could continue operating even in the case of an oil import stop.

Sources: Twitter thread by Janis Kluge, [18] DW article (in German), [19] local news (in German)[20]

3. Shortages during World War II. During big wars, countries must often react to strong, unanticipated shocks to both demand and supply. Ilzetzki (2022) shows that for the massive increase in U.S. government procurement of combat aircraft during WWII, this pressure made firms operate more productively, e.g. by adopting previously rejected methods such as moving assembly lines or implementing measures to reduce employee absenteeism. Interestingly, in 1942 civilian economists and industry representatives argued that military planners' war production goals of producing a total of 50,000 aircraft throughout the entire war were "impossible" to achieve.[21] But as Ilzetzki (2022) points out, within a short time frame, the U.S. aircraft industry ended up surpassing production goals by a wide margin, with almost 100,000 planes produced just in a single year, the year 1944.

As an example for supply shocks during WWII, Germany faced a major petrol crisis as it was cut off from main suppliers like the US or the USSR. Prioritising the highly volume-efficient petrol for military purposes, many civilian vehicles were fitted with a simple device that burned wood into gas, which subsequently was funnelled into its (mostly unmodified) internal combustion engine – see Figure 4. By the end of the war up to 500,000 civilian vehicles are estimated to have been running on wood (compared to 600,000 military vehicles used during the initial attack on the Soviet Union).

Sources: Wikipedia Article on Wood Gas

[18] Twitter: Janis Kluge, https://twitter.com/jakluge/status/1502974281361285120

[19] DW: "Wie man das Druschba-Desaster am Ende der Pipeline wahrnimmt", 02 July 2019, https://www.dw.com/de/wie-man-das-druschba-desaster-am-ende-der-pipeline-wahrnimmt/a-49440013 (content only in German)

[20] Leipziger Volkszeitung: "Raffinerie Leuna von Öl-Stopp betroffen – Versorgung gesichert", 26 April 2019, https://www.lvz.de/Region/Mitteldeutschland/Raffinerie-Leuna-von-Stopp-der-Druschba-Pipeline-betroffen (content only in German)

[21] Ilzetzki (2022) writes: "At the time, this was viewed as a nearly impossible task, with economists Robert Nathan and Simon Kuznets estimating that the US didn't have the productive capacity to meet this aim." He quotes a similar statement by a Ford Motor Company executive from the time as well as that of a historian: "Nobody had yet found a way to bring mass-production techniques to airplane building, and prospects for doing so did not look promising." Also see Smith (1959) pp.154

Figure 4: Car in Berlin 1946. See the "boiler" and the pipe that funnels the extracted wood gas into the internal combustion engine.

4. Ball-bearings production in World War II. During WWII, ball-bearings were a crucial component in tanks, airplanes, machine guns, heavy artillery, and submarines. With the goal of stopping Germany's war machine, the US bombed Schweinfurt, a small town in Germany where about 50% of the German production of ball-bearings took place. Reports point to a 34%-38% decrease in production of ball-bearings in September 1943 (compared with production pre-attacks), after the first bombings in August of the same year. However, the machinery was not as damaged as the factory structures, so they were able to spread the production across other regions of Germany, and there were some available stocks which combined with imports from Sweden minimized the impact of the attacks. Moreover, they redesigned war equipment to substitute with other types of bearings when needed. Reports at the time point to no effect on essential war production due to the bombings.

Sources: Twitter thread by Joachim Voth, Twitter thread by John Cochrane, National Museum Of American History, Business Insider article, United States Strategic Bombing Survey Summary Report, 30 September 1945

Harrison (2020)

5. German U-boat campaign against Britain during World War I. Since the beginning of WWI, Germany conducted U-boat (submarine) campaigns with the goal of preventing merchant ships from arriving in Britain. In an attempt to disrupt Britain's food supplies and force them to surrender before the possible entry of the US in the war, Germany launched an unrestricted U-boat campaign in 1917. This blockade was very close to being successful, with Britain's wheat stock falling sharply. However, Britain was able to survive. This success was the result of careful management, mandatory government enforced rationing, the increase of internal production (possible by dedicating more land to agriculture), and the prioritization of wheat cargo. Moreover, with the help of the US, Britain was able to minimize the consequences of the unrestricted U-boat company (1917-1918): through changed routes, merchant

ships would arrive in groups protected by warships, which made U-boat attacks difficult.

Nonetheless, with the pressure to increase internal agricultural production, Britain needed to find a way around the smaller number of available horses and mechanical tools. To overcome these problems, the government initiated a tractor scheme, importing tractors from the US and also buying internally produced tractors. Additionally, with men being drafted to the war, the labor force decreased and many of those trained to work in agriculture were no longer available. This led to an increase in women's participation in the agriculture labor force, facilitated by available training to work in farms.

Sources: Twitter thread by Joachim Voth, Imperial War Museums, Harwich Haven: Surrender & Sanctuary, National Farmers' Union

Gompert et al. (2014)

Russell (2008)

6. Face Masks During the Covid-19 Pandemic. During the initial months of the Covid-19 pandemic there was a global shortage of face masks. People quickly substituted to using cloth masks in non-clinical settings, while some companies that did not previously produce medical protection adjusted their production process towards produce masks or face shields.

7. Global Microchip Shortage 2020-present. The automotive industry is an important user of integrated circuits (IC), also known as "microchips", using about 15% of its global production. In modern vehicles, these chips are used in an ever broader range of functions: they control when to inflate airbags, manage transmission or the engine status, and intervene as part of extensive sensor systems if drivers lose control. Even mundane functionalities like controlling the AC require microchips. Recent car models also feature sophisticated infotainment and assisted driving systems, all based on IC components.

During the Covid-19 pandemic both the production and sales of vehicles dropped considerably. Car manufacturers hence slashed orders for microchips. However, as demand for cars rebounded, carmakers have been struggling hard to find enough microchip supply to keep their production lines running, partially because of competing demand from the consumer electronics industry that saw increased demand for home entertainment.

Given this seemingly bleak situation, car manufacturers have come up with a surprising way to deal with the microchip shortage: They simply ship cars with some non-vital microchip components missing, sometimes promising customers to install them at a later date against a discount. The following examples demonstrate how dealers receive perfectly driveable and sellable cars, albeit stripped of some gimmicks: Ford shipping cars without AC control from the rear seats, GM shipping SUVs without wireless smartphone charging, HD radios, or fuel management modules, similar adjustments by Renault, Nissan, Cadillac, or BMW. Peugeot has exchanged digital speedometers for analog units.

8. Substituting for single-use plastic. A concern in the current debate on stopping Russian gas imports is that gas is an important input in the chemicals industry in particular in plastics

production. It is therefore instructive to consider past experiences of substituting for plastics.

In recent years, given environmental concerns manifested in consumer demand or legislation, a significant number of firms across different industries has been "forced" to reduce the use of single-use plastic. Supermarket chains have been focused on finding alternatives to plastic bags. Across Asia, supermarkets like Lotte Mart, Saigon Co.op and Big C are replacing plastic wrappers around fruit and vegetables with banana leaves as well as studying the possibility of using this technique in other products.[22] Valorlux, a Luxembourgian non-profit company, has developed what they call a "superbag", a bag made of resistant fabric that is recyclable and washable. The goal of this bag is to replace the single-use bags used to carry vegetables and fruit. An article at RTL Today states that this bag is starting to be sold in 10 supermarket chains in Luxembourg and the French supermarket chain Auchan is expanding its use to other countries, like Portugal as stated in a Sol article. Clothing stores (and other stores) have also replaced their plastic bags, mostly with paper ones, like Zara.

Other innovative solutions arise in the cosmetic and hygiene industry, with L'Oréal replacing the classic liquid shampoo with solid shampoos, so that instead of plastic they can be wrapped in carton. Also driven by the need of reducing plastic packaging, the Portuguese coffee company Delta has started producing coffee capsules/pods from manioc, corn and sugar cane, yielding 100% biodegradable packaging and replacing ones made from plastic or aluminium.[23]

Restaurants are no exception. The reduction of single-use plastic has been counteracted by using classic tableware that can be washed and reused, but also by replacing plastic straws or cutlery by replicas made from paperboard or wood/bamboo. According to a Forbes article, companies in the US like DeliveryZero and GreentoGo are working with restaurants to deliver food in reusable containers, which are returned and then used for further deliveries. More examples are McDonalds and Wagamama in the UK, that have stopped providing plastic straws and replaced them with alternatives based on paperboard. Also in the UK, Burger King has stopped offering plastic toys to kids and is placing bins to collect old plastic toys for recycling, turning them into restaurant play areas or items such as trays.

B.2 Substitution in the Macroeconomy

In Bachmann et al. (2022) we study the potential impact of a stop of Russian energy imports on the German *macro*economy. However, many arguments in the current policy debate focus on very *micro* physical production processes, with industry leaders claiming that substitutability of Russian energy imports is very close to zero. We argue that this micro "engineering view" of substitution is too narrow and misses important mechanisms through which the macroeconomy would adapt to an import stop, for example through business destruction and creation.

[22] According to a Bublle (US online marketplace) article, "Leaf Your Plastic Packaging for Eco-Friendly Banana Leaves", 26 August 2019, https://bubblegoods.com/blogs/news/leaf-your-plastic-packaging-for-eco-friendly-banana-leaves and a Sol article "Folhas de bananeira substituem plástico em supermercados na Ásia", 14 June 2019, https://sol.sapo.pt/artigo/660793/-folhas-de-bananeira-substituem-plastico-em-supermercados-na-asia- (content only in Portuguese)

[23] Sol: "As cápsulas de café amigas do ambiente", 16 May 2019, https://sol.sapo.pt/artigo/658521/as-capsulas-de-cafe-amigas-do-ambiente (content only in Portuguese)

We instead emphasize a more appropriate "economic view" of substitution that includes these additional adjustment mechanisms of the macroeconomy.

The "engineering view" of substitution. In the current debate, many discussions of substitution focus on particular production processes at a very micro level. The following simple example represents this "engineering view" of substitution. Imagine an economy that produces one final good, bottles, that can only be assembled by one specific machine, which can only be delivered by a specific truck, that can only be constructed with four wheels. And wheels are imported from abroad. In this economy with no substitution, a shock to a specific input fully propagates through the supply chain, even if the input represents only a tiny fraction of the overall value of the entire supply chain: if the imports of wheels from abroad decline by 10%, the production of trucks will decline by 10%, leading to 10% fewer machines being delivered, leading to 10% less bottles being produced, i.e. 10% less production of every single good.

If we apply this logic to the expected shock of a ban of Russian gas imports, this means that, in the total absence of substitution, a 30% reduction in gas imports would lead to a 30% decline in national income. However, we next argue that this narrow view misses important mechanisms through which the macroeconomy would adapt to an import stop.

The "economic view" of substitution. The economic view of substitution is broader than this engineering view. It holds that even if substitution is completely impossible at the very micro level this does not necessarily mean that there is no substitution in the aggregate economy.

The key observation is that the substitution may happen at a higher level than the individual production process or even individual firm: in response to a large enough energy supply shock, single production processes that are too reliant on gas or even entire firms may temporarily halt production or may ultimately become non-viable, i.e. they may not survive. While this idea may appear dramatic, in part, it simply represents the functioning of the market economy: production processes or firms that are too reliant on gas and thus too expensive will be replaced by new processes or firms that are better-adapted to the new environment with a smaller gas supply; alternatively, Germany may simply switch to importing some of the goods that become too expensive to produce domestically because they use gas upstream in the production chain (e.g. fertilizer). This substitution at the macro level is thus similar to the process of creative destruction that is important for generating long-run growth.

Technically, single production processes may be very close to displaying a zero elasticity of substitution (Leontief); but they may still aggregate up to an economy with a positive and potentially much higher elasticity of substitution. The observation that zero or low substitution at the micro level does not necessarily imply low substitution at the macro level goes back to a classic paper by Houthakker (1955) who showed that an economy in which individual firms that have Leontief production technologies (i.e. individual elasticities of substitution of zero) can aggregate up to a Cobb-Douglas aggregate production function (i.e. an aggregate elasticity of substitution of one). More generally, it is a classic result in macroeconomic theory that the

elasticity of substitution increases with the level of aggregation.

The apparent lack of substitutability is thus a classic "micro-to-macro fallacy" (of which there are a number in economics). It also provides a straightforward explanation for why many industry representatives seem to believe that the world is one of little substitution (a "Leontief world"): they are actually right at the micro-micro level and this "engineering viewpoint" biases them to also view the macroeconomy in this fashion. (Of course, the alternative explanation for the apparent belief is simply industrial lobbying.)

A concrete example. For an example of how zero substitutability at the production process-level does not necessarily imply zero substitutability for the aggregate economy, consider the following twitter thread by Christian Bayer about the electric furnace steel industry (in German): https://twitter.com/christianbaye13/status/1504785656815497226?s=21.

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