International Trade of Essential Goods During a Pandemic

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Abstract

This paper studies the role of international trade of essential goods during a pandemic. We consider a multi-country, multi-sector model with essential and non-essential goods. Essential goods provide utility relative to a reference consumption level, and a pandemic consists of an increase in this reference level. Each country produces domestic varieties of both types of goods using capital and labor subject to sectoral adjustment costs, and all varieties are traded internationally subject to trade barriers. We study the role of international trade of essential goods in mitigating or amplifying the impact of a pandemic. We find that the effects depend crucially on the countries' trade imbalances in essential goods. Net importers of these goods are relatively worse off during a pandemic than net exporters. The welfare losses of net importers are lower in a world with high trade barriers, while the reverse is the case for net exporters. Yet, once a pandemic arrives, net exporters of essential goods benefit from an increase in trade barriers, while net importers benefit from a decrease in them. These findings are consistent with preliminary evidence on changes in trade barriers across countries during the COVID-19 pandemic.

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1 Introduction

The ongoing COVID-19 pandemic has led to a massive increase in the demand for essential medical equipment to combat it. For instance, goods such as masks, gowns, gloves, and respirators, among others, are playing a key role in allowing healthcare workers to address the ongoing pandemic. While supply has been gradually increasing to try to satisfy the high demand for these goods, countries are starting to face supply shortages and being increasingly forced to ration these goods.

Amidst the growing fear of supply shortages on these essential goods, countries have been resorting to trade policy. According to Evenett and Winters (2020), "as they scramble to find medical supplies to tackle COVID-19, some countries are eliminating their restrictions in imports while others are curtailing their exports."[1] That is, while some countries are lowering their import trade barriers to ease access to these goods, others are making it harder for their domestic firms to sell these goods internationally. Indeed, we document that the heterogeneous response of trade policy across countries is systematically related to the extent to which countries are net importers or net exporters of essential medical goods. According to data collected by Global Trade Alert as of April 24, 2020, 86% of the countries with a trade surplus in these goods have recently imposed restrictive export policies, while only 46% of the countries with a trade deficit have done so.

These findings suggest that international trade plays a fundamental role in the cross-country impact of a pandemic. In this paper, we investigate the role of international trade of essential goods in mitigating or amplifying this impact. In particular, to what extent is the impact of a pandemic heterogeneous across countries depending on whether they are net exporters or net importers of these essential goods? And what is the impact of alternative trade barriers across these countries in the short vs. long run? We address these questions using a dynamic quantitative general equilibrium model with multiple countries and multiple sectors.

While the paper is certainly motivated by and applied to the ongoing COVID-19 pandemic, the implications of our analysis extend well beyond the specific case of trade in essential medical goods during a pandemic. Our approach allows us to investigate the role of trade in any type of essential good that might be subject to shocks. For instance, to the

[1]See Baldwin and Evenett (2020) for a detailed analysis of trade policy changes during COVID-19.

extent that agricultural goods are essential for the survival of a country's population, our analysis can be extended to examine the impact of a pest that might destroy a country's agricultural production.

We thus begin the paper by investigating the patterns of trade imbalances and trade policy across countries in a range of essential goods broader than those directly necessary to address the COVID-19 pandemic. We consider essential goods as ones that are hard to substitute intertemporally. In particular, we classify food, defense, and medical goods as essential and all other traded goods as non-essential. We then ask: To what extent do trade patterns of and trade policy on these goods vary systematically relative to those for non-essential goods? We document that, in the average country, trade imbalances in food and defense are smaller in absolute value than those among non-essential goods. Moreover, both tariff and non-tariff barriers are systematically higher, on average, among food and defense goods relative to those on non-essential goods. In contrast, the average country runs a systematically larger trade deficit and imposes considerably lower tariffs on medical goods than on non-essential goods.

This evidence shows that international trade patterns and barriers among essential goods are systematically different from those among non-essential goods. Moreover, trade patterns and barriers among goods traditionally considered to be essential such as food and defense are also different from those among medical goods. The latter are proving to be essential during a pandemic but might have not been previously perceived as key from the perspective of international trade policy.

Motivated by the observed cross-sectoral heterogeneity, we set up a model of international trade that allows us to investigate the role of trade of essential goods in the economic impact of a shock to either the demand or supply of these goods. Each country in our model produces domestic varieties of both essential and non-essential goods using capital and labor. All these goods are traded internationally, since both countries consume domestic and imported varieties of essential and non-essential goods. Capital and labor can be reallocated across sectors in response to shocks, but this adjustment is subject to costs. Moreover, we assume that firms are myopic and do not internalize the impact of their production decisions on the welfare of households; in our application, this assumption allows us to capture that firms might not adjust their decisions for the possibility of a pandemic.

We assume that the fundamental difference between essential and non-essential goods is accounted for by differences in household preferences for these goods. While non-essential goods are valued according to a standard logarithmic utility function, we assume that essential goods are valued according to a novel utility function in the spirit of Stone (1954) and Geary (1950). In particular, we assume that utility from essential goods is derived from the consumption of these goods relative to a time-varying *reference level*.[2] While analogous to the subsistence level featured by Stone-Geary preferences, we allow households to consume below the reference level but at an exponentially increasing utility cost. Moreover, the utility obtained from the consumption of essential goods is bounded above, allowing us to capture the limited potential to increase utility from ever increasing consumption of these goods.

We use this model as a laboratory to investigate the role of international trade on the cross-country impact of a global pandemic. Thus, throughout our analysis we interpret essential goods as consisting solely of essential medical goods. We then model a global pandemic as a substantial increase in the reference level relative to the level at which households in both countries derive utility from their consumption of essential goods. Our analysis therefore abstracts from most multifaceted effects of a pandemic (e.g., social distancing policies, infection and death rates, increased unemployment), solely restricting attention to the increased demand for essential goods.

In this preliminary version of the paper, we conduct a simple numerical exercise to illustrate the various mechanisms at play during a pandemic. In particular, we assume that both countries are symmetric throughout except for one dimension: we assume that one country is relatively more productive in essential goods, while the other country is relatively more productive in non-essential goods, leading the former to be a net exporter and the latter to be a net importer of these goods. Our goal in future versions of the paper is to quantify the role of these mechanisms by disciplining the model to match salient features of cross-country data.

We find that a global pandemic in which the reference consumption level of essential goods increases identically in both countries has significantly heterogeneous effects across them. There are two main forces at play. First, given that the production of essential goods is subject to capital and labor adjustment costs, producers of these goods cannot sufficiently reallocate production inputs across sectors to boost production, leading to a substantial

[2] One interpretation of this reference level in the context of essential medical goods is the level of healthcare consumption recommended by healthcare professionals. A pandemic such as COVID-19 can then be interpreted as an increase in this reference level.

increase in their relative price. Then, while the price of essential goods increases to the same extent in both economies, the effect on welfare depends on the countries' sectoral trade imbalances. Both countries earn relatively more for their sales of essential goods, and both countries have to spend relatively more for their purchases of these goods. However, given that the net importer is less productive in essential goods, this country sells relatively less than it purchases, while the reverse is the case for net exporters. As a result, net importers of these goods are relatively worse off during a pandemic than net exporters.[3]

We then conduct an extensive analysis to isolate the forces underlying these findings. We first find that capital and labor adjustment costs play a key role in generating a shortage of essential goods that raises their price, yielding a heterogeneous impact across countries. We then show that our preference specification for essential goods is key to generating a substantial increase in the demand for these goods, hence increasing their price substantially. We also document the importance of ex-ante trade imbalances in essential goods; in a world economy with balanced trade of essential goods, the welfare implications are significantly more muted. We conclude this analysis by showing that the assumption that firms are myopic does not play a key role in accounting for our findings in the current parametrization of the model.

We then investigate the role of international trade policy in mitigating or exacerbating the impact of a pandemic. We find that the level of international trade barriers at the onset of a pandemic can significantly alter the economic implications. Keeping all other parameters unchanged, higher initial trade costs imply that the net importer runs a smaller trade deficit of essential goods in the steady state, while the net exporter runs a smaller trade surplus in these goods. Therefore, while a pandemic continues to lead to a substantial increase in the relative price of essential goods, the relative impact on the home and foreign countries is mitigated. We thus conclude that while higher trade barriers on essential goods may reduce the amount of these goods consumed in the steady state, they mitigate the potential vulnerability of net importers of these goods when a global pandemic hits.

These findings have important implications for the design of international trade policy. Even if countries may benefit on average from having cheaper access to goods, the reliance on international trade might put these countries in a vulnerable position if these goods are

[3]The role of sectoral trade imbalances as an amplification mechanism of shocks to relative prices is akin to their role played in Kohn, Leibovici, and Tretvoll (forthcoming) to account for business cycle volatility differences between developed and emerging economies.

essential and either the supply or demand of these goods is subject to global shocks.

While the previous question is informative about the ex-ante design of international trade policy, it is silent about the impact of trade policy changes implemented once a pandemic hits. We thus conclude our analysis by asking: What is the impact of raising trade barriers in response to a pandemic? In contrast to the previous findings, we now find that raising trade barriers when a pandemic hits can significantly exacerbate the welfare costs for net importers of essential goods while making net exporters of these goods relatively better off. As a net importer of essential goods, the home country's production structure is such that it relies considerably on the foreign country for its consumption of essential goods. Thus, an increase in trade barriers on essential goods exacerbates net importers' already difficult task of meeting the demand for these goods and also makes the relative price of these essential goods even higher.

These results suggest that the design of international trade policy for essential goods may suffer from a time-consistency problem. Net exporters of essential goods may ex-ante prefer to live in a world with low trade costs; but when a global pandemic hits, they might be tempted to renege on their commitments and increase trade barriers. The reverse is the case for net importers of essential goods: they may ex-ante prefer to live in a world with high trade costs on essential goods; but when a global pandemic hits, they might be tempted to renege on their commitments and decrease trade barriers.

Our findings also raise the question of whether countries would benefit from protecting essential sectors such as those that produce defense, food, and medical goods. While protectionism may decrease welfare on average, it might be particularly beneficial to mitigate the negative consequences of relying on other countries for the supply of these essential goods. That is, the argument for the protection of essential sectors might be that free trade reduces the ability of countries to produce those goods in the presence of a national emergency such as a war, a natural disaster or, as is the case today, a global health shock. In general, countries tend to specialize in those goods in which they have comparative advantage. During a global disaster in which a country becomes isolated from its main suppliers, its only option is to start producing goods it would have otherwise imported. It may not be feasible, however, to do so if it does not have some installed capacity already in place to increase domestic production of those goods.

This question has been indeed a recurrent topic of debate in international trade policy and, more specifically, in World Trade Organization negotiations. For instance, the importance of agriculture in global trade led to specific agreements through which governments are allowed to support domestic production via domestic or export subsidies. Moreover, goods such as sugar and steel have been subject to protectionist measures. Most recently, the United States has imposed tariffs on steel and aluminum, alluding to national security reasons.

Our paper raises questions related to a very recent and growing literature on the role of international trade of essential medical equipment during a pandemic. In particular, the shortage of essential medical equipment in countries that depend on imports of these goods during the ongoing COVID-19 pandemic has led to a surge of papers proposing international coordination mechanisms to avoid future shortages. Many of these very recent papers are contributions to the recent VoxEU eBook on COVID-19 and trade policy (Baldwin and Evenett 2020). For instance, Stellinger, Berglund, and Isakson (2020) and others advocate for the role of international trade as an insurance device for those countries that rely on imports of essential goods, and hence are specialized in the production of other types of goods.

Several authors have also emphasized the need for greater international coordination. In particular, Evenett (2020) has proposed an international agreement with export incentives to the main suppliers of essential goods and low import tariffs by the main importers. These arguments were also used in a less recent literature on the role of alliances. A very influential paper on this issue is Olson and Zeckhauser (1966). They develop a model of international cooperation on the basis that countries want to participate in these organizations to provide a public good. The model is applied to the case of NATO, hence focusing on defense as a global public good.

Our modeling framework builds on a large literature that studies international business cycles. In particular, we combine the multi-country framework of Backus, Kehoe, and Kydland (1992) with the multi-sector setups of Mendoza (1995), Schmitt-Grohé and Uribe (2018), and Kohn, Leibovici, and Tretvoll (forthcoming). As in the latter, our model features sectoral adjustment costs in both labor and capital. We extend these setups to model essential goods as different from non-essential goods via differences in their contribution to household utility.

The paper is also related to a recent trade literature studying the short-run and long-run effects of international trade on welfare. In particular, Ravikumar, Santacreu, and Sposi (2019) develop a multi-country two-sector model with endogenous capital accumulation and trade imbalances to evaluate dynamic gains from trade. In contrast to their work, we focus on the implications of a transitory unanticipated shock.

2 Evidence on international trade of essential goods

In this section we investigate the patterns of trade imbalances and trade policy on essential goods across countries. We first examine the extent to which these cross-sectional patterns differ systematically between essential and non-essential goods. Then, we examine the relationship between trade imbalances and trade policy changes on essential medical goods in response to the COVID-19 pandemic.

2.1 Data

International trade flows We collect product-level data on international trade flows at the HS 6-digit level of disaggregation from UN COMTRADE (United Nations Statistics Division 2020). We restrict attention to countries that have a population above one million, which leaves us with a total of 109 countries; these countries account for 96% of world trade and 97% of world GDP.[4] We collect data on both exports and imports of these countries vis-à-vis the rest of the world for the year 2018. Data are in current US Dollars.

We classify the 5,203 products available at this level of disaggregation into four product categories: three essential good categories (defense, food, and medical) and an aggregate of non-essential goods. Defense consists of 20 product codes that include vessels and warships, military weapons, and ammunition, among others. Food consists of 847 product codes that include agriculture and food processing. Medical consists of 71 product codes that include pharmaceuticals, antibiotics, and personal protective equipment. The non-essential sector contains the remaining 4,265 HS 6-digit product codes. Hence, 82% of the products traded are classified as non-essential, while 18% are classified as essential.[5]

[4]Population and GDP data are from the World Bank World Development Indicators (https://datacatalog.worldbank.org/dataset/world-development-indicators).

[5]A complete list of the countries in the dataset and the codes used to classify goods across categories is available for downloaded at `http://github.com/LeiboviciSantacreu/EssentialGoods`.

We focus on two key statistics to document the cross-country pattern of international trade in these goods. For each country i and product category j, we first compute the share of country i's aggregate exports accounted for by product category j, x_i^j as:

$$x_i^j = \frac{X_i^j}{X_i},$$

where X_i^j denotes the value of exports of product j by country i and X_i denotes country i's aggregate exports. We refer to this statistic as the "export share" of these goods. We compute the analogous statistic for imports and refer to it as the "import share" of these goods.

We then compute each country i's trade imbalance in product category j as the ratio between net exports (exports minus imports) and the total amount of trade (exports plus imports) in these goods:

$$\frac{\mathrm{NX}_i^j}{\text{Total trade}_i^j} = \frac{X_i^j - M_i^j}{X_i^j + M_i^j},$$

where M_i^j denotes imports of product j by country i. We refer to this statistic as the "trade imbalance" in these goods. Limitations on the availability of disaggregated output data across countries prevent us from computing trade imbalances relative to output rather than total trade.

Tariffs We obtain data on tariffs from UNCTAD's Trade Analysis Information System (United Nations Conference on Trade and Development 2020). Data are reported at the HS 6-digit product level. We contrast tariffs across countries and product categories, restricting attention to effectively applied tariffs in the year 2018. For each country, we compute tariffs applied by a given country on imported goods in a given product code as the average tariffs on these goods across all source countries. We obtain data on applied tariffs for 93 of the 109 countries we use to document the patterns of international trade flows.

Non-tariff barriers We obtain data on non-tariff barriers from the Non-Tariff Measure database also collected by UNCTAD's Trade Analysis Information System (United Nations Conference on Trade and Development 2020). This database contains information on a range of trade policy instruments, from traditional trade policy instruments, such as quotas and price controls, to regulatory and technical measures related to health and environmental protection. In particular, non-tariff barriers are classified into 16 different categories, which refer to different types of measures (import licensing, quotas, price controls, export restrictions, etc.). For each reporter country, partner, and HS 6-digit product and category, the dataset reports the number of barriers imposed.[6]

The data spans the period from 2012 to 2018, but not all countries report in every year. We keep the latest year for which a country reports implementing a non-tariff measure to a partner. We find that 59 of the 109 countries we focus on report applying non-tariff measures in this period.

We follow UNCTAD and The World Bank (2018) in using these data to compute two summary statistics on the prevalence of non-tariff barriers across countries and product categories. First, we compute a *frequency index* for each country and product category: the share of traded product lines subject to at least one non-tariff barrier. This statistic allows us to capture the share of traded goods subject to non-tariff barriers regardless of their values. Then, we capture the share of traded value subject to non-tariff barriers by computing a *coverage ratio* for each country and product category: the share of a country's total trade (i.e., the sum of exports and imports) of these goods subject to at least one non-tariff barrier.

2.2 Trade imbalances and trade policy on essential goods

Patterns of trade in essential goods We begin our empirical analysis by contrasting the patterns of international trade flows between essential and non-essential goods. To do so, Table 1 reports the average export and import shares as well as the average trade imbalances across countries for each of the four product categories described above.

We observe that trade of non-essential goods accounts for the vast majority of both exports and imports in the average country. In particular, the average shares of exports and imports of non-essential goods are 78% and 83%, respectively. Among essential goods, food is the most traded, accounting for 16% of exports and 10% if imports, respectively. It is followed by trade of medical goods with 3% and 4%, respectively, and then defense.

We document that while the size of trade imbalances is also heterogeneous across product categories, it appears to vary systematically between essential and non-essential goods. In

[6] One salient limitation of this data is that it only provides information on the number of barriers per country and product code, but not on the intensity of these barriers.

Table 1: **Pattern of trade in essential goods**

	Export share (%)	Import share (%)	Trade imbalance (%)
Defense	0.07	0.10	-13.88
Food	16.31	10.09	-5.96
Medical	3.24	3.95	-33.22
Non-essential	77.54	82.84	-14.93

Note: This table reports averages across 109 countries in the year 2018. Sectoral imbalances are computed as net exports relative to total trade. Average trade imbalances are computed trimming the bottom 4% of observations.

particular, we find that trade is relatively more balanced on average in traditional essential goods (food and defense) than in non-essential goods. That is, while all imbalances are negative on average, non-essential goods feature larger trade deficits on average than essential goods.[7]

An exception is observed for trade of medical goods, which features a larger trade imbalance than both non-essential and traditional essential goods. That is, the average country relies heavily on imports of medical goods, with only 17 countries in our sample featuring a surplus in these goods. We thus observe that while countries tend to rely less on other countries to fulfill their demand for traditional essential goods relative to that for non-essential goods, they are very dependent on other countries to satisfy their demand for essential medical goods needed to combat a global pandemic such as COVID-19.

Tariffs We now investigate the extent to which essential and non-essential goods feature systematically different international trade barriers. To do so, Table 2 contrasts summary statistics on the levels of tariffs across product categories.

While average tariffs are low on average across all product categories, we do observe significant heterogeneity both across countries within product categories as well as across product categories. Despite the low average tariff levels, there appears to be significant dispersion across countries, as evidenced by standard deviations across tariffs that are approximately identical to the average values of the tariffs.

Moreover, Table 2 suggests that there are systematic differences across sectors. In par-

[7] Average trade imbalances are computed trimming the bottom 4% of observations. This eliminates countries that report having zero or very low exports in a sector, yielding a trade imbalance (% of total trade) above 95%.

Table 2: Tariffs (%)

	Average	Std. Dev.	Min	Max
Defense	7.2	7.4	0.0	25.0
Food	7.9	7.2	0.0	34.5
Medical	1.7	1.9	0.0	8.3
Non-essential	5.4	4.3	0.0	14.2

Note: This table reports averages across 93 countries in year 2018. All values are expressed as percentages.

ticular, we observe that traditional essential goods (defense and food) feature higher average tariffs than non-essential goods: 7.2% vs. 5.4%. In contrast, we find that tariffs on imports of medical goods are low both in absolute and relative terms. The average country applies a 1.7% tariff, on average, on medical goods, with a maximum of 8.3%. These values are substantially lower than those applied to the other product categories.

These patterns resemble the patterns of trade documented above. It may be the case, however, that countries impose higher tariffs on imports of traditional essential goods, thus leading to lower dependence of the average country on the rest of the world for the consumption of these goods. Or it may be the case that imports of medical products are subject to lower tariffs than the other product categories, which may account for the higher dependence of the average country on international trade to fulfill the demand for these goods.

Non-tariff barriers While tariffs are an important and popular trade policy instrument that are particularly easy to quantitatively compare across countries and goods, countries rely on a variety of other instruments to impose barriers to international trade. Thus, we now compare the prevalence of non-tariff barriers across the different product categories under analysis. To do so, Table 3 reports the average frequency and coverage indexes for each product category.

We find that, according to both indicators, non-tariff barriers are significantly more prevalent on essential than non-essential goods. In particular, more than 90% of the traditional essential goods traded are subject to some type of non-tariff barriers, while this is only the case for 50% of non-essential goods. Similarly, while more than 87% of the import value of traditional essential goods are subject to non-tariff barriers, this is only the case for 64% of

Table 3: Non-tariff barriers

	Frequency index (%)	Coverage index (%)
Defense	90.58	87.73
Food	92.59	92.96
Medical	74.51	86.00
Non-essential	50.21	64.12

the import value of non-essential goods.

Note that medical goods are the least protected type of essential good, with 75% of these products and 86% of these imports subject to non-tariff barriers. Although medical goods are more protected than non-essential goods, this finding suggests that prior to the COVID-19 pandemic, countries might not have considered medical goods as essential in the same way as food or defense.

2.3 Trade of essential medical goods during COVID-19

We conclude this section by investigating the response of international trade policy across countries during the ongoing COVID-19 pandemic. On the one hand, some countries have been imposing export restrictions on medical supplies that are essential to fighting the pandemic. On the other hand, some countries have been implementing trade liberalization policies, mostly in the form of import tariff reductions, to make it easier to import these essential medical goods. We ask: To what extent are these heterogeneous changes in international trade policy systematically related to the countries' patterns of international trade imbalances in these goods prior to the pandemic?

To answer this question, we combine data on import liberalizations and export restrictions from Global Trade Alert with the international trade flow data used above. We find that 29 countries have implemented some type of liberalization on medical products necessary to fight COVID-19, whereas 59 countries have imposed restrictions. Table 4 decomposes these changes across countries based on whether they ran a trade surplus or deficit in essential medical goods in the year 2018.

We find that trade policy changes on essential medical goods in the aftermath of COVID-19 appear to be systematically related with the extent to which countries are net suppliers or

Table 4: Trade of essential medical goods during COVID-19

	Number of countries	Number of countries		Share of countries (%)	
		Import liberalization	Export curbs	Import liberalization	Export curbs
Surplus	22	4	19	18.18	86.36
Deficit	87	25	40	28.74	45.98

Note: Surplus (deficit) refers to countries with positive (negative) net exports in essential medical goods in 2018.

net purchasers of these goods vis-a-vis the rest of the world. In particular, about 86% of the countries that have a surplus in medical equipment have implemented export restrictions, whereas only 46% of those with a deficit of these goods have done so. Similarly, about 18% of the countries with a surplus in these goods have reduced import barriers on these goods, whereas only about 30% of those with a deficit in them them did so.

3 Model

We study a world economy populated by two countries, home and foreign, and two sectors: a sector that produces essential goods and one that produces non-essential goods. Each country produces a domestic variety in each sector. Thus, there are four goods in the world economy: a home and a foreign variety of essential goods, and a home and a foreign variety of non-essential goods. All of these goods are traded internationally.

Each country is populated by five types of representative agents: a household, a producer of domestic essential goods, a producer of domestic non-essential goods, a producer of an essential good composite, and a producer of a non-essential good composite.

While the structures of the two countries are identical, we allow some parameters to be country specific. Thus, throughout the rest of this section we describe each of these agents focusing on the home country, and referring to variables *chosen* by the foreign country with an asterisk ("*"). We refer to variables corresponding to the essential and non-essential goods using subscripts e and c, respectively.

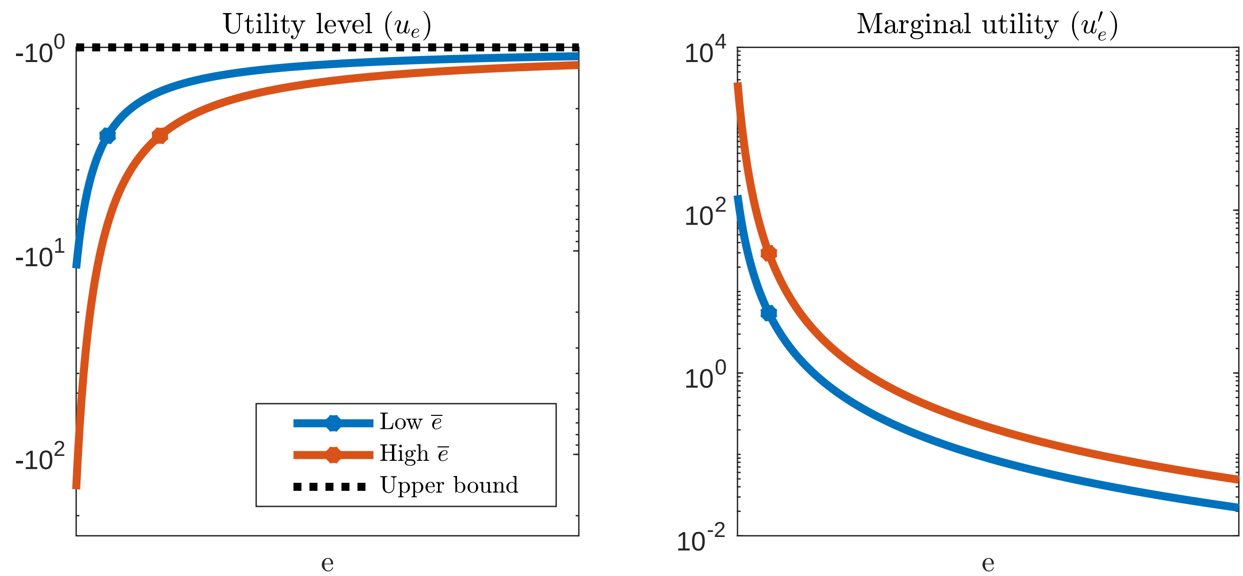


Figure 1: Utility function

3.1 Household

Each country is populated by a representative household who is infinitely lived and discounts the future at rate $\beta < 1$. The household is endowed with one unit of labor that is supplied inelastically at wage rate w_t, and the household also owns domestic producers of essential and non-essential goods. Thus, every period the household earns labor income w_t as well as the profits or losses $\pi_{e,t}$ and $\pi_{c,t}$ incurred by the respective domestic producers. We assume that the household does not have access to international financial markets. The household's budget constraint in a given period is then given by:

$$p_{c,t}c_t + p_{e,t}e_t = w_t + \pi_{c,t} + \pi_{e,t},$$

where $p_{c,t}$ and $p_{e,t}$ denote the price of non-essential and essential goods, respectively, and c_t and e_t denote the consumption of non-essential and essential goods, respectively.

We assume that the household's period utility function is given by:

$$u(c_t, e_t) = \ln c_t - \gamma \exp\left(\frac{\overline{e}_t}{e_t}\right).$$

The parameter γ controls the relative importance of the two goods for the household's utility, and we refer to $\overline{e}_t$ as the "reference level" of essential goods relative to which household consumption of these goods is evaluated. We model this reference level as exogenous and time varying following a stochastic process that we describe below. Notice that period utility is separable in the consumption of essential and non-essential goods. Then, while the level of utility derived from the consumption of non-essential goods is given by standard logarithmic utility, the utility derived from the consumption of essential goods is non-standard.

The goal of this non-standard utility specification is to capture some dimensions along which essential goods might be different from non-essential goods. First, the utility derived from the consumption of essential goods is a function of the ratio between the consumption level e_t and a reference level $\overline{e}_t$ of essential goods. Thus, a given level of essential goods providing high utility levels depends on whether e_t is sufficiently higher than $\overline{e}_t$ rather than on the absolute level of consumption. This captures the idea that households have reference levels for the consumption of essential goods such as food or health services, and a given level of consumption is high or low depending on the comparison with the respective reference level. While akin to the subsistence level featured by Stone-Geary preferences, our specification allows $e_t < \overline{e}_t$. Later in the paper we investigate the impact of changes in this reference level $\overline{e}_t$ to capture an increase in the required amount of essential goods during a pandemic.

Second, while utility derived from the consumption of essential goods is strictly increasing for every $e_t > 0$, the utility level attained features an asymptote at $-\gamma$ for $e_t \to \infty$. This captures the idea that there is a satiation level (in the limit) for essential goods such as food or medical services: increasing levels of food or health services might increase utility marginally, but there is an upper bound to how much they can do so.

Figure 1 plots the utility levels (left panel) and the marginal utilities (right panel) corresponding to a high and low value of $\overline{e}_t$. Notice that essential goods consumed below the reference level are penalized with exponentially decreasing levels of utility. Moreover, higher levels of the reference level $\overline{e}_t$ lead to uniformly lower levels of utility. Thus, given a level of consumption of essential goods e_t, an increase in $\overline{e}_t$ can lead to a substantial decline in utility as well as to a substantial increase in the marginal utility at such consumption level.

The household's problem can be written as:

$$\max_{\{c_t,e_t\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\ln c_t - \gamma \exp\left(\frac{\bar{e}_t}{e_t}\right)\right]$$

subject to

$$p_{c,t}c_t + p_{e,t}e_t = w_t + \pi_{c,t} + \pi_{e,t} \quad \forall t = 0, ..., \infty,$$

where the expectations operator is taken conditional on the information set at time period 0. While the household's decisions are static, we set up the household's infinite horizon problem to ease the computation of welfare effects later in the paper.

3.2 Domestic producers of good $j \in \{c, e\}$

In each sector $j \in \{c, e\}$, a representative firm produces a domestic variety of either non-essential (if $j = c$) or essential (if $j = e$) goods using capital ($k_{j,t}$) and labor ($n_{j,t}$) at a given level of productivity A_j. The amount produced y_j is given by $y_{j,t} = A_j n_{j,t}^{\alpha} k_{j,t}^{1-\alpha}$, where α denotes the share of labor in production; and notice that we assume that sectoral productivity is time invariant and that the technology has constant returns to scale.

Every period firms choose the amount of labor to use in that period and the amount of investment to alter the capital stock in the following period. We assume that investment and the capital stock consist of non-essential goods so that increasing the amount of capital by one unit in the following period requires investing $i_{j,t}$ units of non-essential goods today. Capital depreciates at rate δ, which implies that next period's capital stock $k_{j,t+1}$ is given by $(1-\delta)k_{j,t} + i_{j,t}$.

Given our focus on investigating the adjustment of the world economy for increased demand for essential goods, we introduce capital and labor adjustment costs to help us discipline the degree to which countries can reallocate production across sectors. We assume that capital and labor adjustment costs are quadratic, consist of non-essential goods, and are given by:

$$\phi_k(k_{j,t+1}, k_{j,t}) = \frac{\Omega_k}{2}\left(\frac{k_{j,t+1}}{k_{j,t}} - 1\right)^2$$
$$\phi_n(n_{j,t}, n_{j,t-1}) = \frac{\Omega_n}{2}\left(\frac{n_{j,t}}{n_{j,t} - 1} - 1\right)^2,$$

where Ω_k and Ω_n are positive constants that control the degree to which adjusting production inputs is costly.

The firm's problem then consists of choosing the amount of labor and investment in each period to maximize lifetime discounted profits, where future returns are discounted at rate m_{t+1}. The firm's problem can be expressed as:

$$\max_{\{n_{j,t},i_{j,t},k_{j,t+1},y_{j,t}\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} m_t \left[q_{j,t}y_{j,t} - w_t n_{j,t} - p_{c,t}i_{j,t} - p_{c,t}\phi_k(k_{j,t+1}, k_{j,t}) - p_{c,t}\phi_n(n_{j,t}, n_{j,t-1})\right]$$

$$\text{subject to}$$

$$k'_{j,t} = (1-\delta)k_{j,t} + i_{j,t} \quad \forall t = 0, ..., \infty$$

$$y_{j,t} = A_j n_{j,t}^{\alpha} k_{j,t}^{1-\alpha} \quad \forall t = 0, ..., \infty.$$

Notice that the price of the domestic variety of good j is given by $q_{j,t}$ and that adjustment costs are expressed in units of the non-essential good.

Given our interest in understanding the optimality of production decisions in the context of essential goods, we assume in our baseline model that firms are myopic and do not internalize the impact of their production decisions on the household's utility. Thus, in our baseline model we assume that the rate at which firms discount the future is given by $m_t = \beta^t$. In the quantitative analysis, we investigate the importance of this externality relative to an economy in which firms internalize the impact of production and investment decisions on the utility derived from the consumption of essential goods.

3.3 Producers of composite good $j \in \{c, e\}$

A representative firm produces a composite good $z_{j,t}$ by combining varieties of the good produced in both the home ($z_{j,h,t}$) and foreign ($z_{j,f,t}$) countries. To do so, the firm operates a constant elasticity of substitution technology with elasticity $\sigma > 0$ given by:

$$z_{j,t} = \left[\omega_j z_{j,h,t}^{\frac{\sigma-1}{\sigma}} + (1-\omega_j) z_{j,f,t}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}},$$

where $\omega_j \in (0, 1)$ denotes the relative weight of home vs. foreign goods in the production of the composite good.

The problem of the firm consists of choosing the amounts of inputs $z_{j,h,t}$ and $z_{j,f,t}$ to maximize profits. While the price paid in the home country for the variety of good j produced in that country is given by $q_{j,t}$, the price paid in the home country for the variety produced in the foreign country is given by $\tau_j q^*_{j,t}$, the product of the foreign price and trade costs τ_j. We assume that these trade costs are ad valorem and such that $\tau_j \geq 1$.

The firm's problem in period t is then given by:

$$\max_{z_{j,t}, z_{j,h,t}, z_{j,f,t}} p_{j,t} z_{j,t} - q_{j,t} z_{j,h,t} - \tau_j q^*_{j,t} z_{j,f,t}$$

subject to

$$z_{j,t} = \left[\omega_j z_{j,h,t}^{\frac{\sigma-1}{\sigma}} + (1-\omega_j) z_{j,f,t}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}.$$

3.4 Reference level of essential goods

The process for the time-varying reference level of essential goods $\overline{e}$ is given by:

$$\log \overline{e}_{t+1} = (1-\rho)\log \overline{e} + \rho \log \overline{e}_t + \varepsilon_t$$

where ρ denotes the persistence of the reference level, $\overline{e}$ denotes the steady-state reference level, and $\varepsilon_t \sim N(0, \sigma_e^2)$.

3.5 Market clearing conditions

We let the price of the domestic variety of non-essential goods in the home country $q_{c,t}$ be our numeraire. Then, a *competitive equilibrium of the world economy* consists of:

- prices $\left\{w_t, w^*_t, p_{c,t}, p_{e,t}, p^*_{e,t}, p^*_{c,t}, q_{e,t}, q^*_{e,t}, q^*_{c,t}\right\}_{t=0}^{\infty}$,
- home country allocations $\{c_t, e_t, \pi_{c,t}, \pi_{e,t}, n_{c,t}, n_{e,t}, k_{c,t}, k_{e,t}, i_{c,t}, i_{e,t}, y_{c,t}, y_{e,t}, z_{c,t}, z_{e,t}\}_{t=0}^{\infty}$,
- foreign country allocations $\left\{c^*_t, e^*_t, \pi^*_{c,t}, \pi^*_{e,t}, n^*_{c,t}, n^*_{e,t}, k^*_{c,t}, k^*_{e,t}, i^*_{c,t}, i^*_{e,t}, y^*_{c,t}, y^*_{e,t}, z^*_{c,t}, z^*_{e,t}\right\}_{t=0}^{\infty}$

such that the following conditions hold:

- Home country:

1. Given prices, allocations solve the household's problem
2. Given prices, allocations solve problem of domestic producers
3. Given prices, allocations solve problem of composite good producers
4. Labor market clears: $n_{c,t} + n_{e,t} = 1 \; \forall t$
5. Home essential goods market clearing: $e_{h,t} + \tau_e^* e_{h,t}^* = y_{e,t} \; \forall t$
6. Home non-essential goods market clearing: $c_{h,t} + \tau_c^* c_{h,t}^* = y_{c,t} \; \forall t$
7. Essential composite good market clearing: $e_t = z_{e,t} \; \forall t$
8. Non-essential composite good market clearing:

$$c_t + \sum_{j \in \{c,e\}} \left[i_{j,t} + \frac{\Omega_k}{2} \left(\frac{k_{j,t+1}}{k_{j,t}} - 1 \right)^2 + \frac{\Omega_n}{2} \left(\frac{n_{j,t}}{n_{j,t-1}} - 1 \right)^2 \right] = z_{c,t} \; \forall t$$

- Foreign country:

1. Given prices, allocations solve household's problem
2. Given prices, allocations solve problem of domestic producers
3. Given prices, allocations solve problem of composite good producers
4. Labor market clearing: $n_{c,t}^* + n_{e,t}^* = 1 \; \forall t$
5. Foreign essential goods market clearing: $\tau_e e_{f,t} + e_{f,t}^* = y_{e,t}^* \; \forall t$
6. Foreign non-essential goods market clearing: $\tau_c c_{f,t} + c_{f,t}^* = y_{c,t}^* \; \forall t$
7. Essential composite good market clearing: $e_t^* = z_{e,t}^* \; \forall t$
8. Non-essential composite good market clearing:

$$c_t^* + \sum_{j \in \{c,e\}} \left[i_{j,t}^* + \frac{\Omega_k}{2} \left(\frac{k_{j,t+1}^*}{k_{j,t}^*} - 1 \right)^2 + \frac{\Omega_n}{2} \left(\frac{n_{j,t}^*}{n_{j,t-1}^*} - 1 \right)^2 \right] = z_{c,t}^* \; \forall t.$$

4 Quantitative impact of a pandemic

We use the model presented in the previous section to investigate the impact of a pandemic on a wide range of economic outcomes as well as on welfare. We then evaluate the role played by key ingredients of the model and the model's parametrization on our findings. In the next section, we examine the extent to which international trade policy in the short and long run can impact our findings.

We begin by parametrizing the model presented in the previous section. Our goal is to conduct a numerical exercise in a hypothetical world in which the two countries are fully symmetric except for their productivity in the production of domestic goods. In particular, we assume that the home country is relatively more productive in the production of non-essential goods, while the foreign country is relatively more productive in the production of essential goods.

Thus, in this preliminary analysis we do not quantify the effect of a specific pandemic such as COVID-19. Instead, we use the model to investigate the effect of a generic pandemic in a world in which countries are heterogeneous in their dependence on other countries for their consumption of essential goods.

4.1 Parameterization

To parametrize the model, we partition the parameter space into two groups: a set of predetermined parameters and a set of parameters that we estimate to match moments chosen to ensure that the world economy we study resembles actual economies along some key dimensions.

Predetermined parameters The set of predetermined parameters consists of the discount factor β, the elasticity of substitution between domestic and foreign varieties of the essential and non-essential goods σ, the labor share α, the capital depreciation rate δ, the steady-state reference level $\overline{e}$, capital adjustment costs Ω_k, labor adjustment costs Ω_n, weights ω_e and ω_c, the productivity of the home country in essential goods, and the productivity of the foreign country in non-essential goods. All of these parameters except for the productivities are assumed to be identical across both countries. Table 5 reports the parameter values used throughout.

We set the value of β, σ, α, and δ to standard values from the literature. In particular, we interpret periods in the model as quarters and thus set β to 0.99, which implies a quarterly real interest rate of 1%. Also, we set the elasticity of substitution to 4 following the work of Simonovska and Waugh (2014), implying that domestic and foreign varieties are relatively substitutable.

Table 5: Predetermined parameters

Parameter	Value	Description
A. Parameters common across countries		
β	0.99	Discount factor
σ	4	Elasticity of substitution
α	0.66	Labor share
δ	0.06	Capital depreciation rate
$\bar{e}$	0.40	Reference level of essential goods
Ω_k	50	Capital adjustment costs
Ω_n	50	Labor adjustment costs
$\omega_e = \omega_c$	0.50	Weight on home goods
ρ	0.85	Persistence of shocks to $\bar{e}$
σ_e	0.10	Std. dev. of shocks to $\bar{e}$
B. Country-specific parameters		
$A_e = A_c^*$	1	Sectoral productivities

The remaining parameters are set to illustrate the mechanisms at play. For instance, we set capital and labor adjustment costs Ω_k and Ω_n to 50, allowing us to study an economy in which the adjustment of capital and labor following a shock is neither instantaneous nor zero.[8] Similarly, we set the steady-state reference level $\bar{e}$ to equal 0.40, which given the rest of the parameters yields that shocks to the reference level of essential goods have a significant impact on allocations. We assume the process followed by $\bar{e}_t$ has a persistence ρ equal to 0.85 and a standard deviation σ_e equal to 0.10.

Finally, we normalize to 1 the productivity of the home country in the production of essential goods A_e as well as the productivity of the foreign country in non-essential goods A_c^*. We also set the weights on home goods to $\omega_e = \omega_c = 0.50$.

Estimated parameters The set of estimated parameters consists of the home country's productivity in the production of non-essential goods A_c; the foreign country's productivity in the production of essential goods A_e^*; the weight γ of essential goods in the household's

[8]This parametrization of sectoral adjustment costs is in the range used by Kohn, Leibovici, and Tretvoll (forthcoming) in a similar economic environment.

period utility function; and the international trade costs $\tau_e = \tau_e^*$ and $\tau_c = \tau_c^*$ in essential and non-essential goods, respectively. We assume that $A_c = A_e^*$ such that the two countries are symmetric in all parameters except that they have reverse patterns of productivity across sectors. Thus, there are four parameter values that need to be pinned down.

We choose these four parameter values to ensure that the following moments hold in the home country's steady state: (i) the net exports-to-output ratio in essential goods is equal to -20%, (ii) the share of essential goods in aggregate GDP is equal to 10%, (iii) the import share in essential goods is 25%, and (iv) the import share in non-essential goods is 25%. While these moments are arbitrary, we believe they capture reasonable features of actual economies: (i) some countries run sectoral trade imbalances in essential goods, (ii) the production of essential goods constitutes a small share of aggregate GDP, and $(iii) - (iv)$ the shares of imports in the consumption of essential and non-essential goods are not too high.

The estimated parameters and the model counterpart of the target moments are reported in Table 6. We find that these four parameter values can be chosen to match the four target moments exactly. To do so, the model requires that the home country is more productive in the production of non-essential goods, while the foreign country is more productive in the production of essential goods. The model requires a very low utility weight on essential goods in order to match the low share of essential goods in aggregate GDP. And, finally, to rationalize a 25% import share in each of the goods, the model requires that trade costs on essential goods are considerably higher than those on non-essential goods.

Finally, note that the different specification of the period utility function that correspond to each of the goods combined with the assumption that one country is relative more productive than the other in the production of essential goods (and vice-versa for non-essential goods) implies that the steady-state allocations across countries are asymmetric. The set of estimated and predetermined parameters imply that the foreign country features a trade surplus in essential goods, with these goods accounting for 14% of aggregate GDP. In addition, the foreign country imports a small fraction of essential goods but a very large fraction of non-essential goods.

Table 6: Estimated parameters

Parameter	Value	Description	
$A_c = A_e^*$	1.13	Sectoral productivities	
γ	3.20×10^{-4}	Utility weight on essential goods	
$\tau_e = \tau_e^*$	1.75	Trade costs on essential goods	
$\tau_c = \tau_c^*$	1.36	Trade costs on non-essential goods	
	Targeted		*Untargeted*
	Home country S.S.		Foreign country S.S.
Moment	Target value	Model	Model
NX_e/GDP_e	−0.20	−0.20	0.16
GDP_e/GDP	0.10	0.10	0.14
$\frac{M_e}{p_e e}$	0.25	0.25	0.09
$\frac{M_c}{p_c c}$	0.25	0.25	0.31

4.2 Dynamics following a global pandemic

In the rest of the paper, we use the model as parametrized above to investigate the macroeconomic dynamics following a global pandemic. We model a global pandemic as a shock to the reference level of essential goods $\overline{e}_t$ of the same extent in the two countries. This modeling approach is motivated by the COVID-19 pandemic, where the amount of medical goods required to keep individuals safe and healthy increased suddenly, e.g., protective medical equipment such as sterile gloves, medical protective clothing, protective goggles, and masks. Our analysis therefore abstracts from most multifaceted effects of a pandemic (e.g., social distancing policies, infection and death rates, increased unemployment), solely restricting attention to the increased demand for essential goods.

To examine the effect of an increase in $\overline{e}_t$ in the two countries, we compute impulse response functions following a shock that increases the value of $\overline{e}_t$ by 50% (in logs).[9] Figure 2 plots the impulse response functions of key variables of the model in response to a global pandemic. Each panel plots two lines: a solid line that plots the dynamics of the variable

[9]Throughout the paper we restrict attention to the pruned third-order approximation of the model around its deterministic steady state. All impulse response functions are generalized impulse response functions computed at the ergodic mean.

in the home country, and a dashed line that plots its foreign counterpart. Unless otherwise specified, each panel presents the dynamics of a variable as a log-deviation from its average value.[10] Given the moderate persistence of the shock, as parametrized above, we plot the dynamics over the first 20 periods, when most variables are close to their average values.

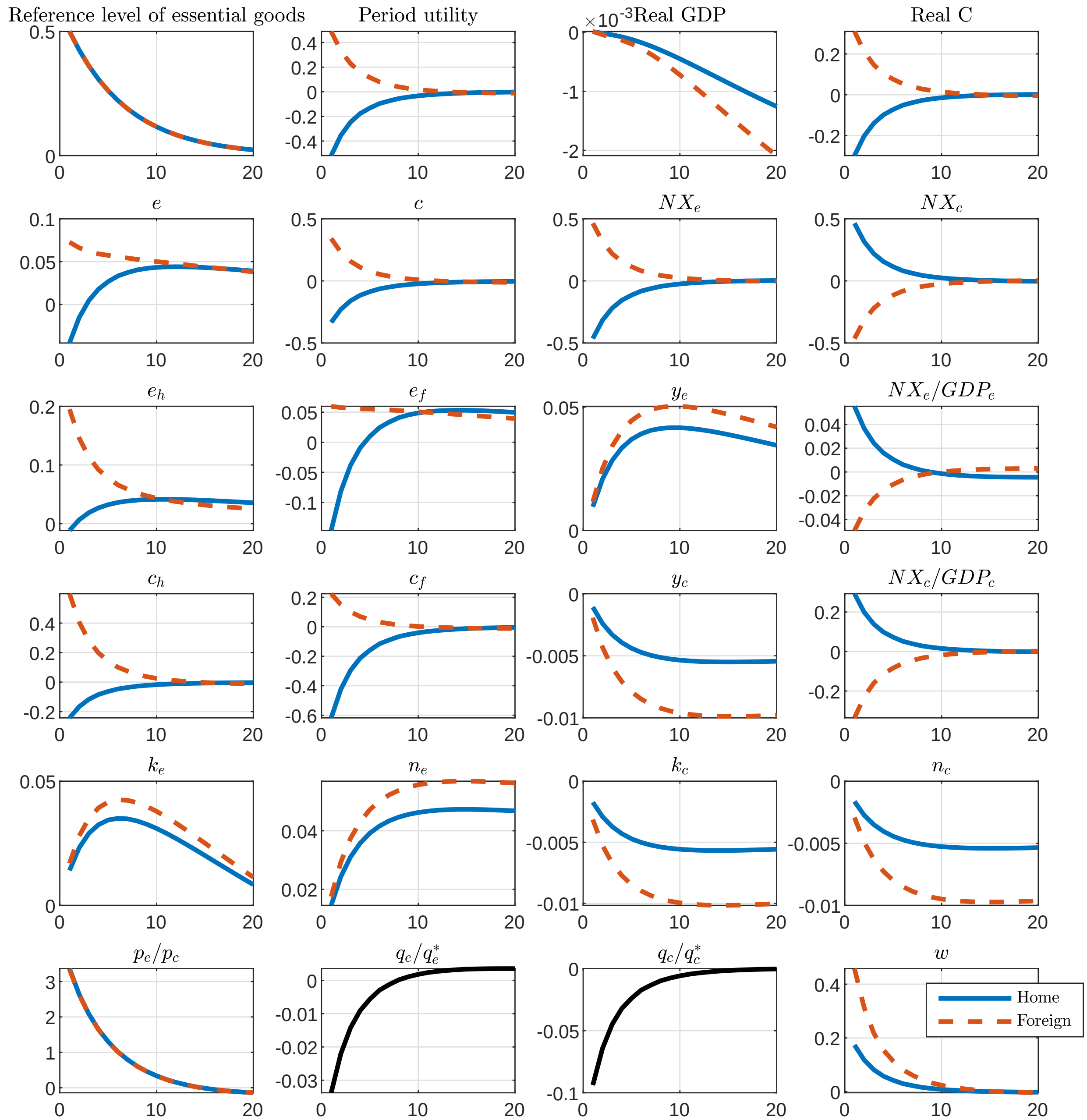
Our key finding is that a global pandemic in which the reference level of essential goods increases identically in both countries nevertheless has significantly heterogeneous effects across them. In each country, the increase in the reference level of essential goods leads to an increase in the demand for these goods; as Figure 1 shows, at any given level of consumption of essential goods, a higher reference level increases the marginal utility of consumption of essential goods.

Given that the production of essential goods in each of the countries is subject to capital and labor adjustment costs, producers of these goods cannot costlessly reallocate production inputs across sectors to boost production of essential goods in sufficient amounts to satiate the higher demand due to the pandemic. Therefore, the excess demand for essential goods leads to a substantial increase in p_e/p_c, the price of these goods relative to non-essential goods.

Now, while p_e/p_c increases to the same extent in both economies, it leads to a persistent decline in the period utility function of households in the home country but to a persistent increase of that of households in the foreign country. Recall that the two countries are symmetric except for their sectoral productivities: the home country is relatively more productive in non-essential goods, while the foreign country is relatively more productive in essential goods. This difference implies that the foreign country is a net exporter of essential goods, while the home country is a net importer of these goods. Thus, a substantial increase in the relative price of essential goods has a negative welfare effect on net importers of these goods but a positive one on net exporters of these goods.

Both countries earn relatively more for their sales of essential goods, and both countries have to spend relatively more for their purchases of essential goods. However, given that the foreign country is the more productive producer of essential goods, this country sells relatively more essential goods than it purchases, thus experiencing a net benefit from the pandemic.

[10] The only exceptions are the four panels depicting the dynamics of sectoral net exports which are expressed in level deviations around their average value.



Note: x-axes denote time periods. x-axes are expressed as log deviations from long-run averages except for the panels featuring net exports or net export- to-GDP ratios, which are expressed as deviations from long-run average levels.

Figure 2: Dynamics following a global pandemic

But how can this country *benefit* from a global pandemic? The substantial increase in the price of essential goods allows foreign households to increase their consumption of domestic and imported essential goods while the country remains a net exporter of these goods. On the other hand, the increased value of exported essential goods allows foreign households to also increase their consumption of non-essential goods, both domestic and imported.

The home country experiences welfare losses from a global pandemic through exactly the reverse forces. As a net importer of essential goods, the increase in the price of essential goods relative to the price of the good produced domestically implies that this country is forced to cut back its consumption of essential goods despite its higher need for them. As aggregate consumption decreases, households in the home country cut their consumption of non-essential goods to reallocate resources to prevent the consumption of essential goods from declining even further.

4.3 Welfare implications of a global pandemic

The discussion and impulse response functions above show that the effects of a global pandemic can be substantially heterogeneous across countries depending on whether a country is a net exporter or net importer of essential goods. Indeed, the analysis above shows that the period utility function increases for net exporters but decreases for net importers of these goods. We now further investigate the welfare implications of a global pandemic by quantifying the lifetime impact of a pandemic in terms of consumption-equivalent units. To do so, for each country we ask: What fraction of the consumption of non-essential goods would a household living forever in the deterministic steady state of the model be willing to give up to avoid experiencing the global pandemic examined in the impulse response functions above?

We present the welfare impact of a global pandemic in the home and foreign countries in the first row of Table 7. Consistent with our findings above, we find that a global pandemic leads to a substantial welfare loss in the home country and to a sizable welfare gain in the foreign country. In particular, an agent living in the deterministic steady state of the home country would be willing to sacrifice 1.77% of consumption of non-essential goods every period to avoid being hit by a global pandemic. In contrast, an agent living in the deterministic steady state of the foreign country would demand her consumption to increase 0.93% every period to deter her from preferring to experience a global pandemic.

A word of caution is in order regarding the interpretation of our quantitative findings. Recall that the quantitative exercise in the current version of the paper is designed to illustrate the mechanisms of the model rather than to obtain a quantification that might be informative about the welfare implications of the COVID-19 or other pandemics. Our goal

Table 7: Welfare implications of a global pandemic

Model	Welfare gain for...	
	Home country	Foreign country
Baseline	-1.77%	0.93%
Low adjustment costs	-1.46%	-0.12%
High adjustment costs	-2.35%	2.44%
Stone-Geary	-3.16%	0.68%
Cobb-Douglas weight	-5.20%	-4.30%
Rational firms	-1.68%	0.86%
No sectoral imbalances	-0.38%	-0.38%
Higher trade barriers	-0.87%	-0.0004%
Raise trade barriers when pandemic hits	-2.16%	1.03%

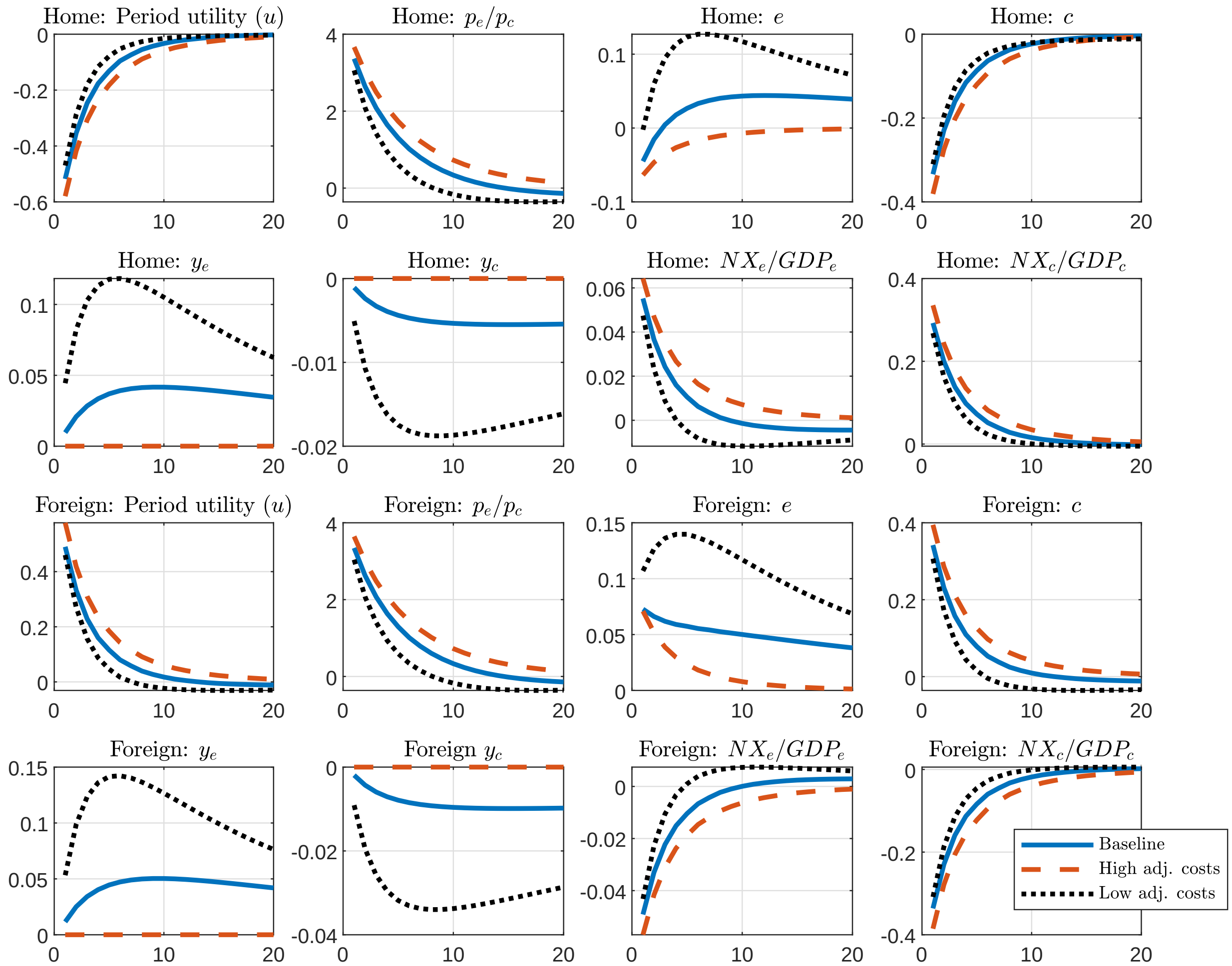
is to eventually quantify these effects by estimating the model to match salient features of the data; future versions of the paper will attempt to bridge this gap and provide welfare estimates that might be more directly applicable to pandemics in actual economies.

4.4 Understanding the mechanism

The results presented in the previous sections show that a global pandemic has substantially heterogeneous effects across countries depending on the extent to which countries are net exporters or net importers of essential goods. We now investigate the role played by various ingredients of the model in accounting for these findings.

4.4.1 Role of adjustment costs

We begin by investigating the role played by the adjustment costs that need to be incurred by producers of essential and non-essential goods, to adjust the amount of capital and labor used in production. To do so, we compute impulse response functions for the global pandemic examined in the previous section under alternative degrees of capital and labor adjustment costs. On one end, we consider an economy with lower adjustment costs on both capital and labor; in particular, we set $\Omega_n = \Omega_k = 10$. On the other end, we consider an economy with



Note: x-axes denote time periods. y-axes are expressed as log deviations from long-run averages except for the panels featuring net exports or net export-to-GDP ratios, which are expressed as deviations from long-run average levels.

Figure 3: Role of adjustment costs

much higher adjustment costs on both capital and labor; in particular, we set $\Omega_n = \Omega_k = 10^6$.

Figure 3 plots the impulse response functions for the baseline model and for the economies with alternative degrees of factor adjustment costs. In contrast to the impulse response functions presented above, each panel now presents the dynamics of a given variable in a given country, and each line in a panel corresponds to a different adjustment cost specification: a solid corresponds to the baseline model, a dashed line corresponds to the economy with high adjustment costs, and a dotted line corresponds to the economy with low adjustment costs. To ease the presentation, we restrict attention to a subset of key variables that allow us to illustrate the main effects.

We find that adjustment costs play a crucial role in accounting for the implications of our baseline model. Insofar as producers of essential and non-essential goods are not able to easily increase the production of essential goods when a pandemic hits, the relative price of essential to non-essential goods increases persistently, leading to the effects described above in our baseline model. Higher adjustment costs then simply reinforce these effects, leading to a higher increase in the relative price of essential goods and, thus, to a larger increase in utility in the foreign country and to a larger decline in utility in the home country. Notice that production of essential and non-essential goods remains approximately unchanged under high adjustment costs. Thus, in this case, the total amount produced of each good remains almost unchanged; so the adjustment only occurs via the reallocation of consumption across countries.

In contrast, in an economy with lower adjustment costs, producers of essential and non-essential goods are able to easily adjust their production in response to changing economic conditions. The relative price of essential goods increases on impact given that capital cannot be reallocated within the period, as investment takes one period to materialize. Yet, after the first period, the relative price of essential goods decreases rapidly as both countries are able to rapidly reallocate their factors of production towards this sector. These effects have very significant implications for the dynamics of utility. While utility increases on impact in the foreign country, the gains rapidly evaporate, declining even below their long-run average values a period after the initial shock; in every period the foreign country is worse off than in the baseline model with higher adjustment costs. In contrast, the reverse is the case for the home country: with low adjustment costs, utility declines relatively less than in the baseline model.

The welfare implications in terms of consumption-equivalent units reported in the second and third rows of Table 7 are consistent with these findings. In particular, households living in the deterministic steady state in the foreign country need to be compensated with 0.93% and 2.44% of consumption of non-essential goods every period in the baseline and high-adjustment-cost economies, respectively, to be prevented from preferring to experience a global pandemic. In contrast, with low adjustment costs, they are willing to give up 0.12% of consumption of non-essential goods every period to avoid experiencing a global pandemic. The effects are reversed for households in the home country, for whom the welfare cost of a pandemic is lower (-1.46%) in an economy with low adjustment costs and considerably higher in an economy with high adjustment costs (-2.35%).

4.4.2 Role of essential good preferences

We now investigate the role played by our specification of the utility derived from the consumption of essential goods relative to a reference level. To do so, we contrast the impulse response functions of our baseline model with those arising from two alternative ways of modeling preferences for essential goods.

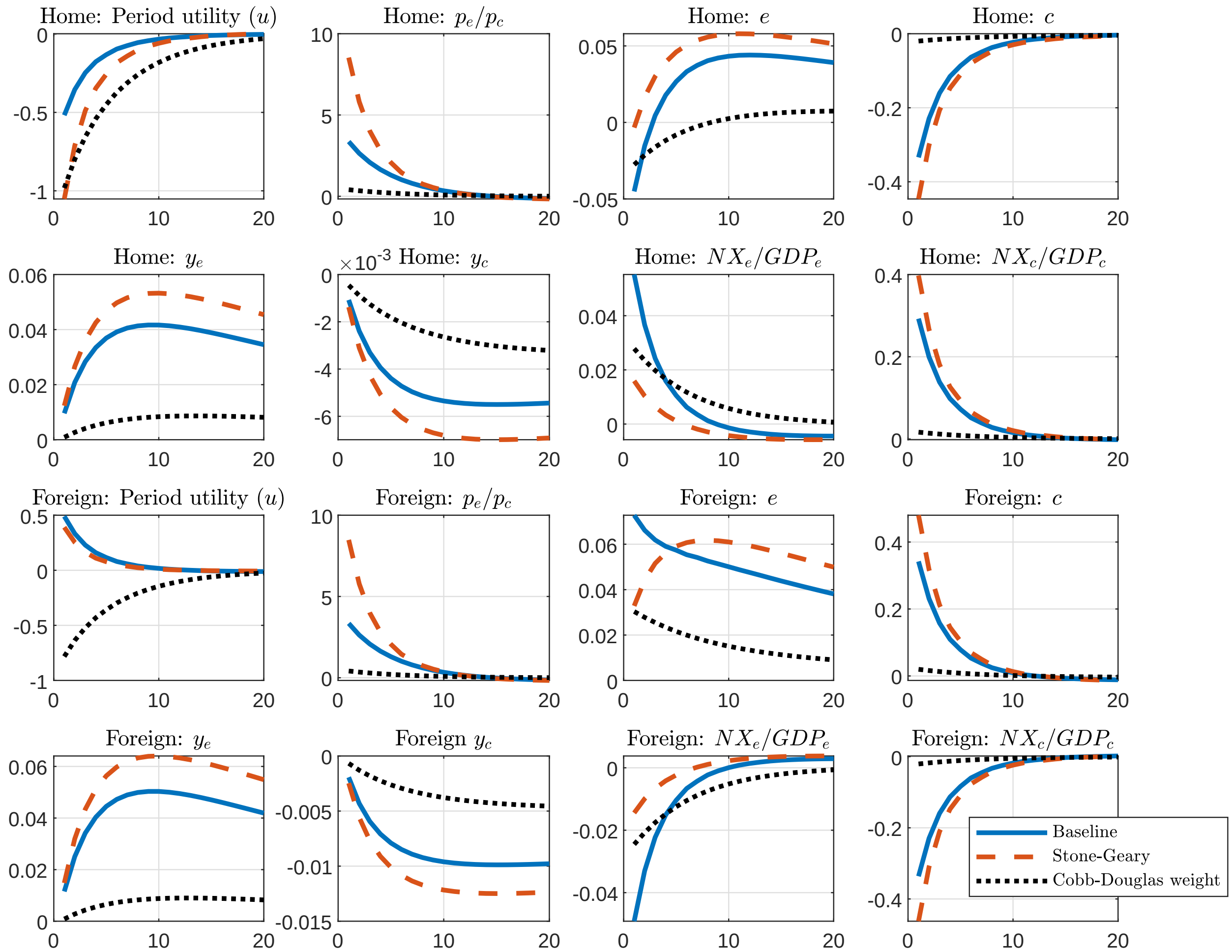
First, we consider an economy with Stone-Geary preferences, where the household's utility function in each country is given by $u(c_t, e_t) = \ln c_t + \gamma \ln(e_t - \overline{e}_t)$. This more standard way of modeling preferences for essential goods features a subsistence level, so we begin by comparing the implications of our model with this alternative specification. However, these preferences are problematic for our purposes, since they are only well defined for $e > \overline{e}_t$, preventing us from considering large shocks to the subsistence level that could lead to levels of consumption of essential goods below subsistence.

Second, we consider an economy that abstracts altogether from featuring a reference or subsistence level. Instead, we assume that preferences for essential goods are symmetric to preferences for non-essential goods: $u(c_t, e_t) = \ln c_t + \gamma \ln e_t$. These preferences are thus Cobb-Douglas. We engineer a pandemic in this economy by shocking the weight γ on essential goods given that this alternative economy has no reference level to shock.

Figure 4 plots the impulse response functions for the baseline model and for the economies with the alternative preference specifications. To keep the magnitudes comparable to those implied by the baseline model, in the model with Stone-Geary preferences, we consider a 10% shock (in logs) to the subsistence level, and we calibrate this level such that $\frac{e-\overline{e}}{e} = 0.20$ in the steady state. For the economy with Cobb-Douglas preferences, we consider a 50% increase (in logs) in γ.

Our findings are twofold. On the one hand, we find that the implications of our baseline model are very similar to those of the analogous model with Stone-Geary preferences. This is reassuring, as our preference specification for that model attempts to capture the role for subsistence featured by Stone-Geary and avoid the sharp kink faced when consumption reaches the subsistence level.

On the other hand, we find that an alternative specification that abstracts from shocks to a reference or subsistence level and, instead, shocks the Cobb-Douglas weight on essential



Note: x-axes denote time periods. y-axes are expressed as log deviations from long-run averages except for the panels featuring net exports or net export-to-GDP ratios, which are expressed as deviations from long-run average levels.

Figure 4: Role of essential good preferences

goods generates considerably milder and qualitatively different effects. The key difference is that even a substantial increase in the weight on essential goods appears unable to generate a considerable increase in the relative price of essential goods despite increasing the demand for these goods. Without significant effects on prices as featured in our baseline model, we then observe that both the home and foreign countries experience a decline in utility when the pandemic arrives. Cursory experimentation with larger shocks to γ appears unable to generate significant effects on prices of the magnitude featured by the baseline model. The welfare implications in terms of consumption-equivalent units reported in the fourth and fifth rows of Table 7 are consistent with these findings. We thus conclude that our preferences that include a reference level for essential goods play a critical role in accounting for the implications of the baseline model.

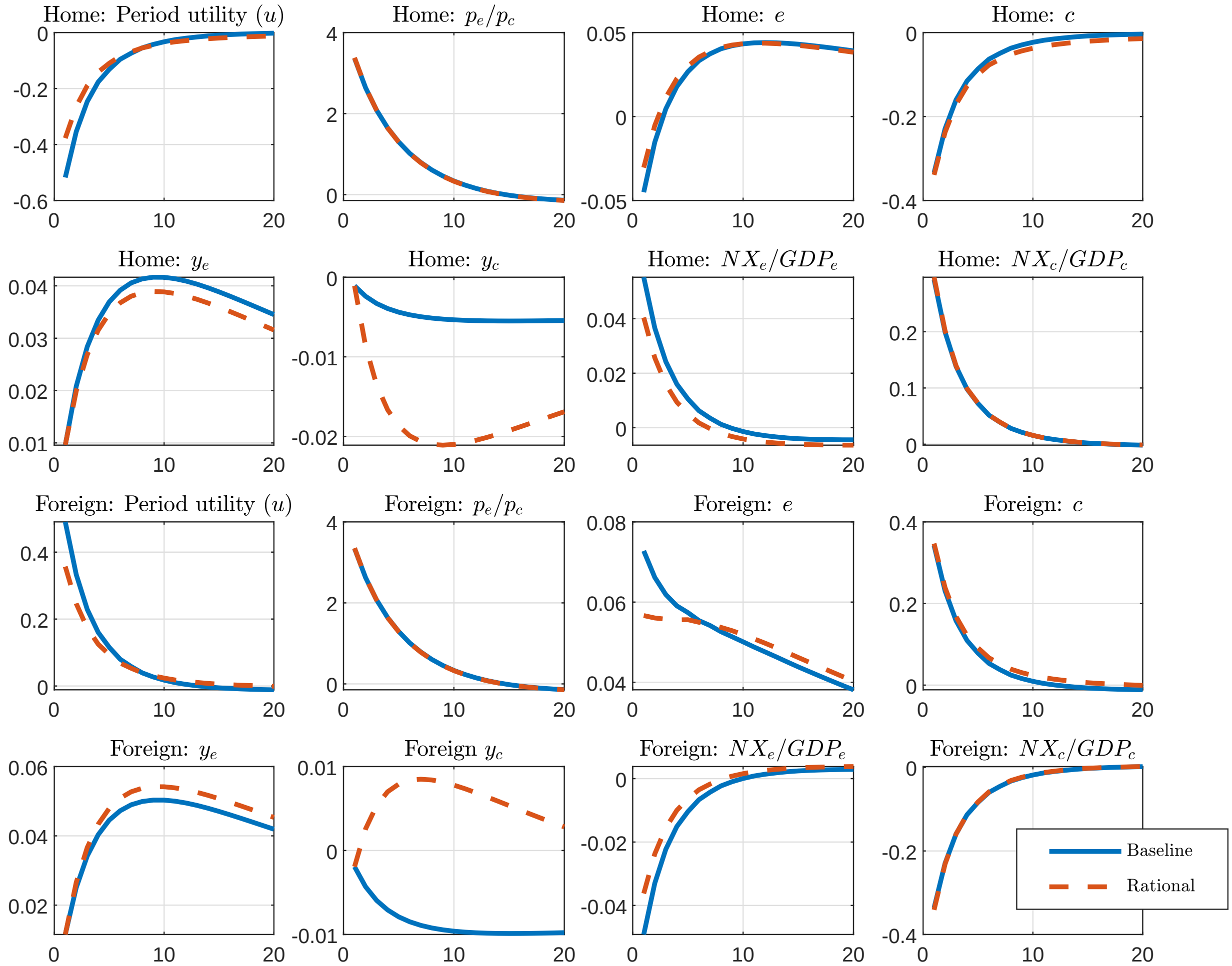
4.4.3 Role of myopic firms

Another dimension that we investigate is the role played by our assumption that producers of both essential and non-essential goods are myopic in their discounting of the future when making hiring and investment decisions. In particular, while households discount the future using a stochastic discount factor that is a function of the relative marginal utilities between consumption today vs. next period, we assume that firms simply discount the future at discount rate β. The goal of this assumption is to introduce a mismatch between the desires of households to ensure a smooth supply of essential goods vis-a-vis the profit maximization motive of producers of such goods. Thus, the model features an externality such that producers of essential and non-essential goods do not internalize the impact of their decisions on the welfare of households.

To investigate the role of this assumption, Figure 5 contrasts the baseline impulse response functions with those arising from a model in which firms discount the future using the household's stochastic discount factor (SDF); we refer to this alternative model as one with "rational" firms. Specifically, we let the SDF in the home country m_t be given by $m_t = \beta^t \lambda_t$, where λ_t is the Lagrange multiplier on the household's budget constraint in period t; the SDF of firms in the foreign country is defined analogously.

We find that the assumption that firms are myopic does not appear to play a fundamental role in accounting for our findings. Most variables respond very similarly both qualitatively and quantitatively in the two models under consideration. Yet, we interestingly find that a pandemic in an economy with rational firms leads to less of a decline in utility in the home country and less of an increase in utility in the foreign county. This is indeed what the welfare implications presented in Table 7 also show.

What accounts for these differential effects? In the economy with myopic firms, producers of essential goods in the home country do not internalize that there are some states of the world (e.g., an increase in the reference level of essential goods) in which producing the essential good would be extremely valuable to the household, even if during normal times producing the essential good in the home country would not be very profitable. Thus, in the economy with myopic firms, producers of essential goods undersupply these goods, and over rely on the foreign country to obtain them.



Note: x-axes denote time periods. y-axes are expressed as log deviations from long-run averages except for the panels featuring net exports or net-export-to GDP ratios, which are expressed as deviations from long-run average levels.

Figure 5: Role of myopic firms

In contrast, in an economy with rational firms, producers of the essential good in the home country do internalize that even if they are not very productive, it might nevertheless be worthwhile to produce this good since there are states of the world in which the household would really benefit from it. These firms then produce more essential goods on average than in the model with myopic firms, and the home country runs smaller trade deficits of essential goods on average when firms are rational. Thus, a pandemic in the home country induces lower welfare losses in the home country under rational firms than under myopic ones; the reverse is the case for the foreign country.

These findings show that whether or not firms internalize the effect of their decisions on the utility of households may affect the welfare implications of the model. More work remains to be done to identify conditions that may induce larger differences in the impulse response functions across these two models.

4.4.4 Role of sectoral trade imbalances

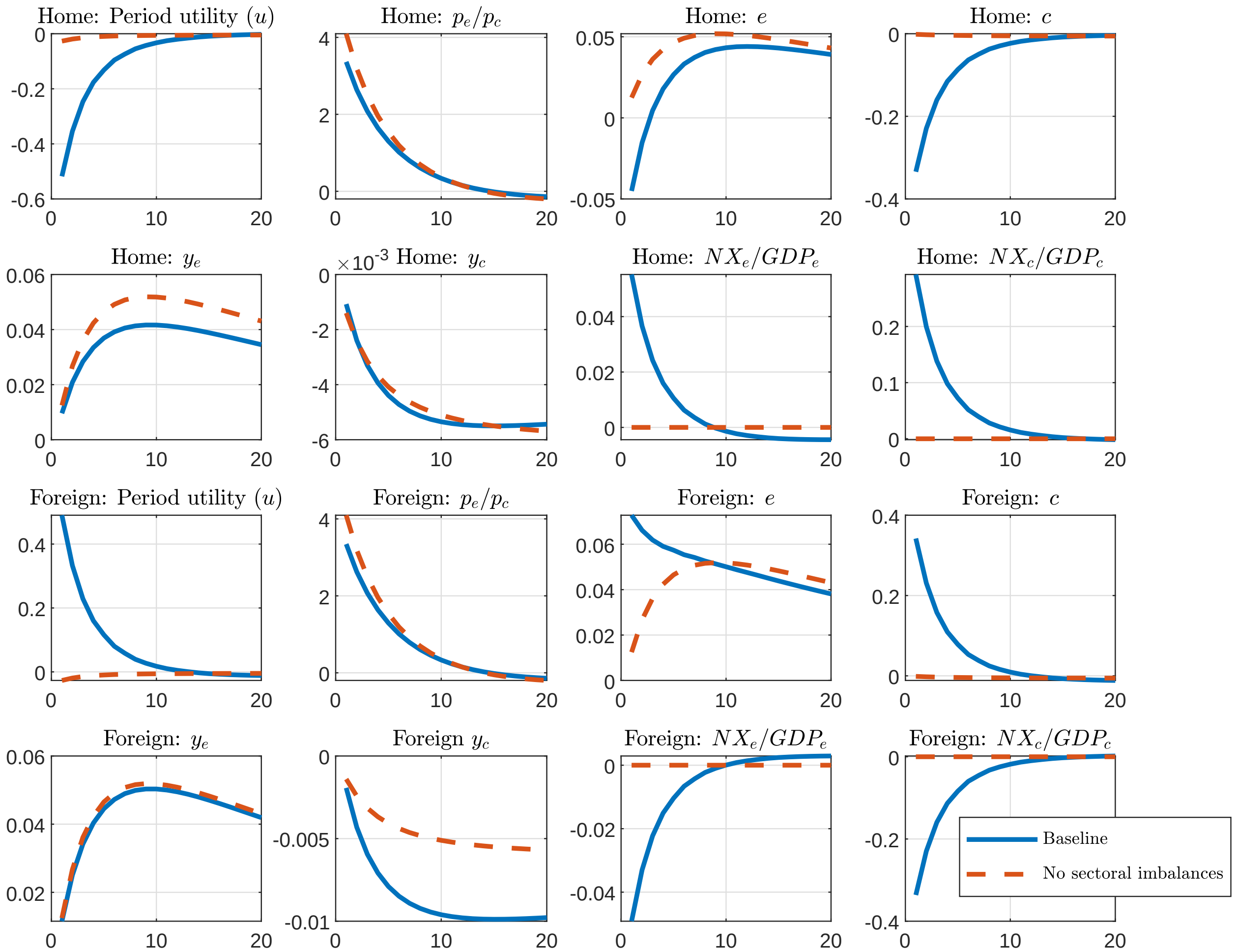
We finally investigate the role played by sectoral trade imbalances on the impact of a pandemic across countries. Our discussion above suggests this is a key channel through which changes in the relative price of essential goods triggers a very heterogeneous response across net exporters and net importers of essential goods. In Figure 6 we contrast our baseline impulse response functions with those of an alternative calibration of our model. We keep the estimation approach as in our baseline except for the targeted sectoral imbalance in essential goods of the home country: we now recalibrate the model such that the home country's trade of essential goods is balanced rather than featuring a deficit as in our baseline calibration.

We find that, while the relative price of essential goods increases even more than in our baseline model, the welfare effect in both countries is significantly more muted. Both countries are now able to increase their consumption of essential goods at the expense of producing and consuming fewer non-essential goods. The home country is thus relatively better off than in our baseline model given it no longer runs sectoral trade deficits in essential goods, while the foreign country is relatively worse off since it no longer benefits from selling its excess production of essential goods internationally. The lifetime welfare effects presented in Table 7 are consistent with these findings.

We thus conclude that sectoral trade imbalances in essential goods play a fundamental role in accounting for the cross-country effects of a pandemic implied by our baseline model.

5 Trade policy and the impact of a pandemic

The previous section shows that international trade plays a fundamental role in accounting for the impact of a pandemic across countries. In a world economy in which producers face costs to adjust capital and labor in the short run, net importers of essential goods might experience severe welfare losses, while net exporters of these good might experience welfare gains. We now investigate the role of international trade policy in mitigating or exacerbating



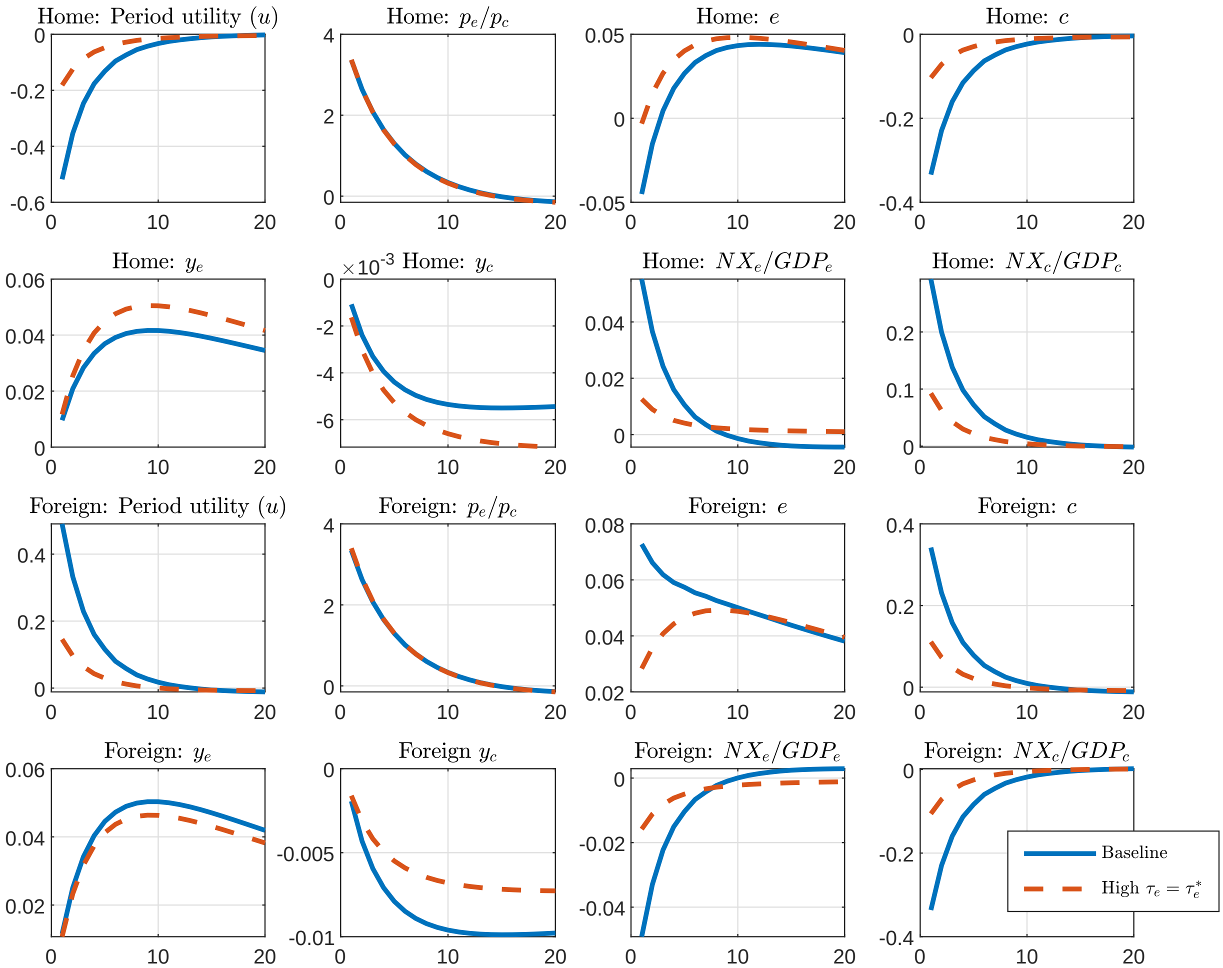
Note: x-axes denote time periods. y-axes are expressed as log deviations from long-run averages except for the panels featuring net exports or net export-to-GDP ratios, which are expressed as deviations from long-run average levels.

Figure 6: Role of sectoral trade imbalances

the impact of a pandemic.

5.1 A pandemic in a world with low vs. high trade barriers

We begin by examining the extent to which the long-run level of international trade barriers at the onset of a pandemic affects its impact on economic outcomes. To do so, Figure 7 contrasts the baseline impulse response functions examined in the previous section with their counterparts from a model featuring higher trade barriers on essential goods. In particular, we consider a world economy in which $\tau_e = \tau_e^* = 3$ (vs. $\tau_e = \tau_e^* = 1.75$ in the baseline), keeping all other parameters unchanged from their baseline values.



Note: x-axes denote time periods. y-axes are expressed as log deviations from long-run averages except for the panels featuring net exports or net export-to-GDP ratios, which are expressed as deviations from long-run average levels.

Figure 7: A pandemic in a world with low vs. high trade barriers

We find that differences in international trade barriers at the onset of a pandemic can significantly alter the economic implications of a pandemic. Keeping all other parameters unchanged, higher trade costs imply that the home country runs a smaller trade deficit of essential goods in the steady state, while the foreign country runs a smaller trade surplus in these goods. Therefore, while a pandemic continues to lead to a substantial increase in the relative price of essential goods, the relative impact on the home and foreign countries is mitigated by higher trade barriers. As the home country runs a smaller trade deficit in essential goods, the increase in the price of essential goods leads to a smaller decline in the utility of households in this country. Conversely, the smaller trade surplus in these goods in the foreign country implies that this country benefits relatively less from a pandemic than in the baseline model. These effects indeed translate to substantially mitigated welfare implications of a pandemic, as shown in Table 7.

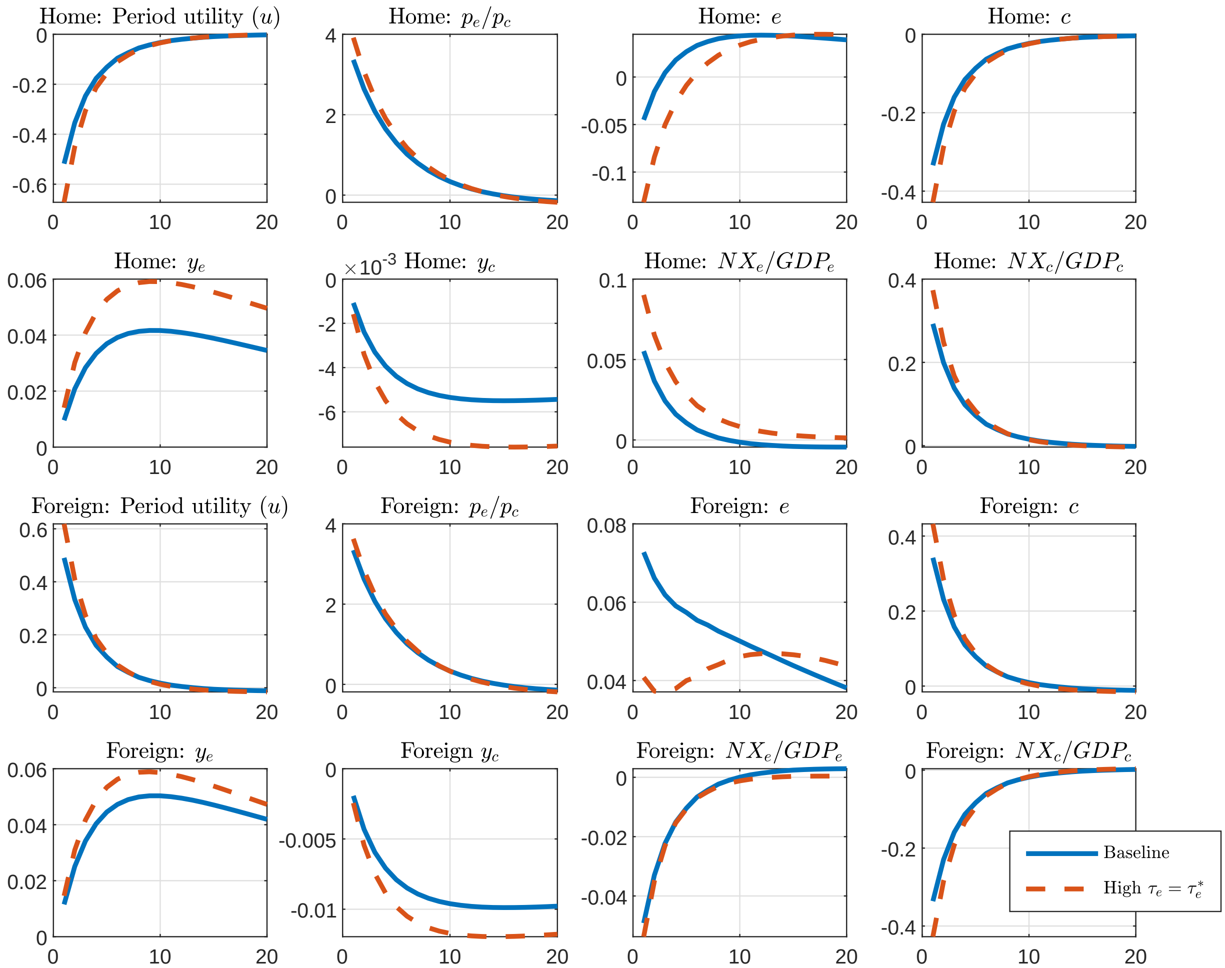
We thus conclude that while higher trade barriers on essential goods may reduce the amount of these goods consumed in the steady state, they mitigate the potential vulnerability of net importers of these goods when a global pandemic hits. These findings have important implications for the design of international trade policy. Even if countries may benefit on average from having cheaper access to goods, the reliance on international trade might put these countries in a vulnerable position if these goods are essential and either the supply or demand of these goods is subject to shocks. Thus, these findings raise the following question: To what extent should countries protect, if at all, goods that are essential and whose demand or supply may be subject to shocks? We will address this and other related questions in future versions of the paper.

5.2 A pandemic in a world that raises trade barriers

While the previous question is informative about the design of international trade policy from an ex-ante perspective, it is silent about what countries should do once a pandemic hits. We thus ask: Given some level of trade barriers prevalent in the world when a pandemic hits, what is the impact of raising these barriers in responses to the pandemic? Our answer to this question might help us interpret the policy response of several countries over the first few weeks of the COVID-19 pandemic, when they raised the trade barriers on essential medical equipment.

To answer this question, Figure 8 contrasts our baseline impulse response functions with those implied by our baseline model when a pandemic is accompanied by a simultaneous increase in international trade barriers on essential goods in both countries of 0.50 log points relative to their steady-state values.[11] Our findings contrast sharply with the results presented in the previous subsection. We now find that raising trade barriers when a pandemic hits can significantly amplify the welfare implications in both countries; these effects can be observed both directly via the period utility plotted in the figure and via the welfare implications provided in Table 7. As a net importer of essential goods, the home country's

[11] We assume the increase is transitory and returns back to the steady state at the same rate as the reference level of essential goods $\overline{e}_t$.



Note: x-axes denote time periods. y-axes are expressed as log-deviations from long run averages except for the panels featuring net exports or net export-to-GDP ratios, which are expressed as deviations from long-run average levels.

Figure 8: A pandemic in a world that responds by raising trade barriers

production structure is such that it relies considerably on the foreign country for its consumption of essential goods. Thus, if trade barriers on essential goods are raised when the pandemic hits, they exacerbate the shortages of these goods the home country already faces and raises the relative prices of these goods even higher.

The exacerbated welfare losses of the home country when trade barriers are increased in the short run during a pandemic contrast sharply with the mitigated welfare loss of the country in a world with persistently higher trade barriers, as examined in the previous subsection. The reason is simply that persistently higher trade barriers make the home country less reliant on international trade for the consumption of essential goods, while a short-run increase in international trade barriers in a world with capital and labor adjustment costs exacerbates the impact of a higher price of essential goods on the country because it cannot rapidly adjust its production structure to the changes in demand.

These findings suggest that the design of international trade policy for essential goods may suffer from a time-inconsistency problem. Net exporters of essential goods may ex-ante prefer to live in a world with low trade costs; but when a pandemic hits, they might be tempted to renege on their commitments and increase trade barriers. The reverse is the case for net importers of essential goods; they may ex-ante prefer to live in a world with high trade costs on essential goods; but when a pandemic hits, they might be tempted to renege on their commitments and decrease trade barriers. We will investigate these issues further in future versions of the paper.

6 Concluding remarks

This paper studies the role of international trade of essential goods during a pandemic. In particular, we investigate the extent to which trade of essential goods mitigates or amplifies the impact of a pandemic and the degree to which these effects depend on international trade policy both in the short and long run.

Our findings so far suggest that the effects of a pandemic across countries depend crucially on countries' trade imbalances in essential goods. Net exporters of essential goods can experience welfare gains during a pandemic, while net importers can experience significant welfare losses. The welfare losses of net importers are lower in a world with high trade barriers, while the reverse is the case for net exporters. Yet, once a pandemic arrives, net exporters of essential goods benefit from an increase in trade barriers, while net importers benefit from a decrease in them. These findings are consistent with preliminary evidence on changes in trade barriers across countries during the COVID-19 pandemic.

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