

# Shortages of Critical Goods in a Global Economy: Optimal Trade and Industrial Policy

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## Abstract

This paper studies shortages of critical goods in a global economy and the role for policy. We develop a dynamic general equilibrium model of trade with producers of essential and non-essential goods owned by heterogeneous households under incomplete markets. A global increase in demand for critical goods increases prices and production, but there is underinvestment relative to an economy with a representative household or complete markets. Trade exacerbates the shock as producers reallocate domestic sales toward exports. Shortages can be mitigated, increasing welfare, by taxing exports while subsidizing imports and production. These policy changes are consistent with cross-country evidence during COVID-19.

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## 1 Introduction

After decades of trade liberalization, the world is experiencing a return to protectionism. Recent events like the COVID-19 pandemic, the Russian invasion of Ukraine, and growing geopolitical tension between the U.S. and China have exposed the vulnerability of modern economies to heavy dependence on imports of critical goods such as personal protective equipment, commodities, and semiconductors. Shortages of these goods in the aftermath of recent global shocks have raised questions about the potential role for policy interventions to mitigate them.

Despite significant specialization of production across countries, domestic firms are often capable of adjusting production decisions to mitigate the impact of such shortages. However, firms may not sufficiently adjust production if social returns and private costs are misaligned, introducing a role for policy. In this paper, we study the response of critical goods producers to global shortages of these goods and the potential for policy interventions to mitigate them.

To do so, we set up a quantitative dynamic general equilibrium model of international trade with multiple sectors, heterogeneous households, and incomplete markets. We use the model to investigate whether optimal trade and industrial policies can be used to address global shortages of critical goods. We examine this question quantitatively by focusing on a specific application: shortages of essential medical goods during the outbreak of COVID-19. We find that trade and industrial policies can be an effective way to unilaterally address shortages of critical goods in an open economy. Moreover, we show that our findings are consistent with data on the use of trade and industrial policy during COVID-19.

We study a small open economy that produces domestic varieties of essential and non-essential goods and trades them with the rest of the world. Essential and non-essential goods are combined to produce final goods with a constant elasticity of substitution (CES) technology. We model essential goods as contributing to the production of final goods relative to a time-varying reference level, capturing the level of demand or need for these goods. Thus, an increase in the reference level can be interpreted as an increase in the amount of essential goods required to produce final goods — e.g., an increase in the need for personal protective equipment during COVID-19, an increase in the prevalence of semiconductors in the production of goods, etc.

Essential and non-essential goods are produced by firms that accumulate capital and hire labor subject to adjustment costs. These firms are owned by a unit measure of households

that populate the economy. Households have imperfect access to financial markets and are endowed with a unit of labor and an ownership share of either essential or non-essential goods producers. Motivated by recent evidence on the prevalence of entrepreneurship and private businesses, we assume that firm ownership is not perfectly diversified across households.<sup>1</sup> Thus, the forward-looking decisions of essential and non-essential goods producers are undertaken with profit flows discounted based on their respective owners' stochastic discount factor. In particular, firms need not necessarily discount the future with a socially-representative stochastic discount factor.

We model shortages of essential goods as arising from a global increase in their demand, but the analysis is analogous for the case in which shortages arise from decreased supply. Domestically, the economy experiences an increase in the reference level of essential goods. Internationally, the economy experiences an increase in the price of imports and exports of essential goods. The higher domestic and export prices of essential goods lead producers to increase the production scale. But as owners borrow to finance the adjustment of production capacity, incomplete financial markets lead them to trade off current consumption for higher future consumption, reducing their discount rate and lowering the returns to the increased scale. Thus, the economy features underinvestment and underhiring in response to shortages of essential goods relative to one without ownership heterogeneity or one with complete financial markets.

We use our model to quantify the impact of global shortages of essential goods and to study the role for trade and industrial policy interventions. We focus on a specific application: shortages of essential medical goods during COVID-19. We estimate the model to match salient features of the U.S. economy prior to and during the COVID-19 pandemic. In particular, we focus on shortages of essential medical equipment and supplies that have been critical to combat COVID-19 throughout the first year of the pandemic, prior to the development and distribution of vaccines. Thus, we model the pandemic as an increase in the reference level of essential goods, along with an increase in export and import prices, to capture the higher global need for medical equipment. We assume the pandemic lasts for one year, is unexpected, and that the full path of shocks back to steady-state is observed

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<sup>1</sup>See Cooper et al. (2016), Asker, Farre-Mensa, and Ljungqvist (2015), Dinlersoz et al. (2018), Smith et al. (2019), Guntin and Kochen (2021) for recent studies on the prevalence of private businesses and entrepreneurship in the U.S. Limited stock market participation (Poterba et al. 1995, Guvenen 2006, Chien, Cole, and Lustig 2012) also suggest firm ownership is not perfectly diversified.

once the pandemic is realized.

Our estimates imply that essential goods and non-essential goods are complementary and that capital investment and hiring are subject to significant adjustment costs. These imply that households are unable to reduce demand for these goods by substituting them with non-essential goods and that firms are unable to rapidly scale up production. Moreover, we find that, while domestic producers of essential goods increase production, much of it is exported given the higher global price of these goods. Therefore, these forces exacerbate the shortages arising from the underinvestment and underhiring caused by the misalignment of producer vs. social discount rates.

We then investigate the role for trade and industrial policy interventions to mitigate the impact of shortages of essential goods. We endow the government with three policy instruments: an import subsidy, an export tax, and a production subsidy. The government's problem consists of unilaterally choosing one-time changes to these instruments for the duration of the pandemic to maximize utilitarian social welfare when the shocks are realized. We restrict attention to policies that do not involve direct redistribution of resources across households, abstracting from standard redistributive motives for policy interventions. Moreover, we choose the relative contribution of each household to social welfare to ensure there is no role for policy interventions in the pre-pandemic steady-state.

We discuss our key findings in steps. In the absence of industrial policy, the government finds it optimal to simultaneously restrict exports of essential goods with an export tax of 14.26% while introducing an import subsidy of 9.44%. Export taxes allow the government to reallocate the sales of essential goods from exports toward domestic consumers, while import subsidies allow households to increase purchases of foreign varieties. However, total production decreases, as export taxes reduce the returns to investment and hiring. The net impact of these policies is to increase welfare by increasing domestic and foreign consumption of essential goods, mitigating the negative impact of the pandemic.

In the absence of trade policy, the government finds it optimal to encourage production of essential goods with a 12.23% total sales subsidy. Production indeed increases, but its impact on consumption of essential goods is very limited: While industrial policy is effective at encouraging production of essential goods, the increased output is largely exported rather than sold domestically.

While both trade and industrial policies are individually effective at mitigating shortages

of essential goods, the gains from introducing these policies are significantly amplified when introduced jointly. Specifically, when endowed with both types of policies, the government finds it optimal to introduce a 25.02% export tax, an 18.28% import subsidy, and a 27.97% total sales subsidy. Indeed, we find that trade and industrial policies jointly increase the consumption of essential goods across most households without discouraging the production of essential goods. Industrial policy provides an incentive to increase production, and trade policy realigns firms' incentives to sell the increased production domestically.

These findings are consistent with policy interventions in the U.S. in the aftermath of COVID-19. For instance, government resorted to the Defense Production Act to increase production of personal protective equipment and vaccines, while restricting the extent to which the increased production could be sold internationally (Bown 2022).

We then investigate the key ingredients underlying the role for trade and industrial policy in our economy. First, we show that there is no role for policy interventions in the pre-pandemic steady-state, or in the absence of household heterogeneity. Second, we show that intra- and inter-temporal complementarities are quantitatively important in accounting for our findings — policies that promote production and consumption of essential goods have a lower payoff if households find it easier to reallocate consumption across time or sectors. Third, we show that sectoral adjustment costs are also quantitatively important, suggesting that firms' production decisions are more sensitive to these than socially optimal. Finally, financial market frictions are also critical, as they connect each household's SDF with their own idiosyncratic borrowing decisions, creating a role for policy interventions.

We conclude by contrasting our findings with evidence on trade and industrial policy interventions across countries during COVID-19. Specifically, we use data from Global Trade Alert for February 2020 to January 2021 on policies introduced to regulate trade and production of goods critical to combat COVID-19, as classified by the World Trade Organization. We find that governments around the world pervasively introduced export restrictions, import liberalizations, and production incentives on COVID-19 related goods. We interpret these policy interventions as consistent with the implications of our model. Moreover, we also document systematic differences in the likelihood of introducing these policies based on pre-pandemic trade dependence across country-product pairs — we show these patterns are also consistent with the implications of the model.

Our paper contributes to a large literature that studies the optimal design of trade policy

in open economies with heterogeneous firms. For instance, Costinot, Rodríguez-Clare, and Werning (2020) and Demidova and Rodríguez-Clare (2009) study optimal unilateral trade policy in static small open economy models with heterogeneous firms. In contrast to much of the literature, our paper studies the role for optimal trade policy interventions arising purely from distortions in the dynamic response to shocks, rather than from long-run distortions in the allocation of production and trade across countries.

Our analysis also contributes to a literature that studies the effectiveness and desirability of industrial policy as a tool to encourage production in sectors perceived to be undersupplied. For instance, Itskhoki and Moll (2019) study the role for industrial policies to aid in the process of economic development in an environment with heterogeneous firms subject to financial frictions. Closer to our analysis, Caballero and Lorenzoni (2014) study the role for industrial policy in response to shocks in an open economy with multiple sectors and heterogeneous firms subject to financial frictions. In contrast to these studies, we study the implications for trade and industrial policy in an economy where the role for interventions arises from incomplete financial markets and household heterogeneity in the types of firms that they own.

Our paper is also related to recent studies on the aggregate importance of small but systemic sectors. Baqaee and Farhi (2019b) show, in a static economy, that small sectors can be systemically important if the elasticity of substitution between them and other production inputs is low and factors of production are fixed. Baqaee and Farhi (2019a) extend this analysis to a standard static model of international trade. We study the policy implications of related forces using a dynamic environment with goods that are essential for either consumption or production, with production decisions subject to distortions.

Finally, our paper is most closely related to recent studies of shortages of critical goods during crises and the potential for policy interventions. For instance, Traiberman and Rotemberg (2022) and Grossman, Helpman, and Lhuillier (2021) study the role for policy interventions ex-ante rather than ex-post, as we do in our work. Similarly, Eppinger et al. (2021) study the impact of alternative policies ex-post following recent supply chain disruptions. Shortages of critical goods during COVID-19 have also led to a surge of papers proposing international coordination mechanisms (Stellinger, Berglund, and Isakson 2020; Acharya et al. 2020; Evenett 2020; Baldwin and Evenett 2020) as well as domestic industrial policies (Athey et al. 2022; Bown 2022; Bown, Snyder, and Staiger 2022) to avoid future shortages.

A broader set of papers has also recently studied the role of international trade as a transmission channel for pandemic-related shocks across countries (Cakmakli et al. 2021; Bonadio et al. 2020; LaBelle, Leibovici, and Santacreu 2021; Antràs, Redding, and Rossi-Hansberg 2020).

## 2 Model

We study a small open economy that trades goods and financial assets with the rest of the world. Goods are produced domestically and abroad in two sectors: essential and non-essential. We denote variables corresponding to these sectors using subscripts  $e$  and  $n$ , respectively. Thus, the small open economy has access to four types of varieties: a domestic and imported variety of essential goods, and a domestic and imported variety of non-essential goods. We let domestic varieties of non-essential goods be the numeraire. All of these goods are traded internationally. Varieties in each sector are produced using labor and capital, which are mobile across sectors. The economy is populated by five types of agents: households, producers of sectoral varieties, producers of sectoral composite goods, producers of final goods, and a government.

### 2.1 Households

The economy is populated by a unit measure of infinitely-lived households who discount the future at rate  $\beta < 1$ . There are two types of households who differ in their source of income: Households of type  $i \in \{n, e\}$  are endowed with  $\lambda_i$  units of labor and own producers of the domestic variety of good  $i$ , where  $\lambda_n + \lambda_e = 1$ . Labor is supplied inelastically at wage rate  $w_t$ . Thus, every period households earn labor income  $\lambda_i w_t$  as well as the profits or losses  $\pi_{it}$  of the respective domestic producer. In addition, every period households receive lump-sum transfers  $\mathcal{T}_{it}$  from the redistribution of revenue collected by the government through import tariffs, export taxes, or sales taxes implemented by the government.<sup>2</sup>

As in Bewley-Huggett-Aiyagari models, we assume that households have access to incomplete financial markets.<sup>3</sup> They can trade a one-period risk-free bond vis-a-vis each other as well as with the rest of the world subject to bond-holding costs. The bond is denominated in units of the numeraire and trades at an exogenous interest rate  $r$  that is time-invariant. Following Schmitt-Grohé and Uribe (2003), households' bond-holding choices  $b_{it+1}$  are subject to a quadratic bond-holding cost  $\frac{\Omega_b}{2} (b_{it+1} - \bar{b}_i)^2$  denominated in units of non-essential

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<sup>2</sup> $\mathcal{T}_{it} < 0$  denotes a lump-sum tax.

<sup>3</sup>See Bewley (1977), Huggett (1993), and Aiyagari (1994).

goods, where  $\Omega_b$  is a constant that controls the cost of holding bonds above their steady-state level, and  $\bar{b}_i$  denotes the household-specific steady-state level of bond-holdings.

The budget constraint of household  $i \in \{n, e\}$  in period  $t$  is given by:

$$p_t c_{it} + b_{it} + p_{nt} \frac{\Omega_b}{2} (b_{it+1} - \bar{b}_i)^2 = \lambda_i w_t + \pi_{it} + \frac{b_{it+1}}{1+r} + \mathcal{T}_{it},$$

where  $c_{it}$  denotes consumption of final goods,  $p_t$  denotes the price of final goods, and  $p_{nt}$  denotes the price of the non-essential good composite.<sup>4</sup>

Household  $i$ 's period utility function is given by  $u(c_{it}) = \frac{c_{it}^{1-\xi}}{1-\xi}$ , where  $1/\xi$  is the intertemporal elasticity of substitution. Then, household  $i$ 's problem can be written as:

$$\max_{\{c_{it}, b_{it+1}\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{c_{it}^{1-\xi}}{1-\xi}$$

subject to

$$p_t c_{it} + b_{it} + p_{nt} \frac{\Omega_b}{2} (b_{it+1} - \bar{b}_i)^2 = \lambda_i w_t + \pi_{it} + \frac{b_{it+1}}{1+r} + \mathcal{T}_{it} \quad \forall t = 0, \dots, \infty,$$

where the expectation operator is conditional on the information set in period  $t = 0$ .

## 2.2 Rest of the world

The rest of the world is the trade and financial partner of the domestic economy. On the one hand, it produces a differentiated imported variety in each sector  $j \in \{n, e\}$ , which is sold at a perfectly elastic price  $p_{jt}^m$  and subject to a sector-specific iceberg trade cost  $\tau_j$ . These are the domestic economy's imports. On the other hand, the rest of the world has a perfectly elastic demand for the domestic economy's varieties in each sector  $j \in \{n, e\}$  at price  $p_{jt}^x$ . These are the domestic economy's exports. Finally, the rest of the world is the financial counterpart of the domestic economy, with a perfectly elastic demand or supply of bonds at interest rate  $r$ .

## 2.3 Producers of domestic variety in sector $j \in \{n, e\}$

In each sector  $j \in \{n, e\}$ , a representative firm produces a domestic sectoral variety using capital  $k_{jt}$  and labor  $\ell_{jt}$ , with a time-invariant productivity  $A_j$ . The amount produced in each sector  $j$  is given by  $A_j (\ell_{jt}^\alpha k_{jt}^{1-\alpha})^\eta$ , where  $\alpha$  controls the labor share,  $1 - \alpha$  controls the

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<sup>4</sup>Under this formulation,  $b_{it+1} > 0$  denotes debt and  $b_{it+1} < 0$  denotes savings.



capital share, and  $\eta \in (0, 1)$  denotes the degree of decreasing returns to scale.<sup>5</sup>

In every period  $t$ , firms choose the amount of labor to use in that period and the amount of capital investment for production in period  $t + 1$ . Each sector's investment and capital stock are made up of non-essential goods. To increase the amount of capital by one unit in the following period requires investing  $I_{jt}$  units of non-essential goods today. Given that capital depreciates at rate  $\delta$ , next period's capital stock  $k_{jt+1}$  is  $(1 - \delta)k_{jt} + I_{jt}$ .

We introduce sectoral capital and labor adjustment costs to help us discipline the degree to which sectoral production can be changed over time. We assume that capital and labor adjustment costs are quadratic and denominated in units of non-essential goods:

$$\begin{aligned}\phi_{k_j}(k_{jt+1}, k_{jt}) &= \frac{\Omega_{k_j}}{2} \left( \frac{k_{jt+1}}{k_{jt}} - 1 \right)^2 \\ \phi_{\ell_j}(\ell_{jt}, \ell_{jt-1}) &= \frac{\Omega_{\ell_j}}{2} \left( \frac{\ell_{jt}}{\ell_{jt-1}} - 1 \right)^2,\end{aligned}$$

where  $\Omega_{k_j}$  and  $\Omega_{\ell_j}$  are non-negative sector-specific constants.

The representative firm produces a differentiated variety that is sold domestically and abroad. The firm chooses domestic sales subject to a downward-sloping demand function from domestic producers of composite goods. Exports are chosen subject to the perfectly elastic demand from the rest of the world at price  $p_{jt}^x$ . Export revenues are subject to an ad-valorem tax rate  $\tau_{jt}^x$ , and total sales are subject to an ad-valorem subsidy  $\tau_{jt}^y$ .<sup>6</sup>

Then, the firm's problem consists of choosing labor, investment, and market-specific prices and quantities in each period to maximize lifetime discounted profits given initial capital stock  $k_{j0}$ , where returns are discounted at rate  $m_{jt}$ :

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<sup>5</sup>We assume the production technology features decreasing returns to scale to ensure the existence of a steady state with positive exports across a nondegenerate set of parameters.

<sup>6</sup>Negative export taxes denote export subsidies, and negative sales subsidies denote taxes.

$$\begin{aligned}
& \max_{\{\ell_{jt}, i_{jt}, k_{jt+1}, p_{jt}^d, y_{jt}^d, y_{jt}^x\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} m_{jt} \left\{ (1 + \tau_{jt}^y) p_{jt}^d y_{jt}^d + (1 + \tau_{jt}^y - \tau_{jt}^x) p_{jt}^x y_{jt}^x - w_t \ell_{jt} - p_{nt} I_{jt} \right. \\
& \quad \left. - p_{nt} \phi_{kj}(k_{jt+1}, k_{jt}) - p_{nt} \phi_{\ell j}(\ell_{jt}, \ell_{jt-1}) \right\} \\
& \text{subject to} \\
& k_{jt+1} = (1 - \delta) k_{jt} + I_{jt} \quad \forall t = 0, \dots, \infty \\
& y_{jt}^d + y_{jt}^x = A_j \left( \ell_{jt}^\alpha k_{jt}^{1-\alpha} \right)^\eta \quad \forall t = 0, \dots, \infty \\
& y_{jt}^d = \omega_j \left( \frac{p_{jt}^d}{p_{jt}} \right)^{-\sigma} y_{jt} \quad \forall t = 0, \dots, \infty \\
& y_{jt}^x \geq 0 \quad \forall t = 0, \dots, \infty,
\end{aligned}$$

where  $p_{jt}^d$  and  $p_{jt}^x$  denote the domestic and export price of the domestic variety in sector  $j$ , while  $y_{jt}^d$  and  $y_{jt}^x$  denote their respective quantities;  $m_{jt}$  denotes household  $j$ 's stochastic discount factor, who owns producers of domestic varieties of good  $j$ . The third constraint consists of the demand function faced domestically, which results from the problem of producers of composite good  $j$  described below.<sup>7</sup> Given the perfectly elastic demand faced from the rest of the world, the fourth constraint is required to ensure exports are weakly positive.

## 2.4 Producers of composite goods $j \in \{n, e\}$

A representative firm produces a composite good  $y_{jt}$  by combining varieties of the good produced domestically ( $q_{jt}^d$ ) and abroad ( $q_{jt}^m$ ). To do so, the firm operates a constant elasticity of substitution technology given by:

$$y_{jt} = \left[ \omega_j q_{jt}^d \frac{\sigma-1}{\sigma} + (1 - \omega_j) q_{jt}^m \frac{\sigma-1}{\sigma} \right]^{\frac{\sigma}{\sigma-1}},$$

where  $\omega_j \in (0, 1)$  denotes the relative weight of domestic vs. imported goods in the production of the composite good, and  $\sigma > 0$  denotes the elasticity of substitution between domestic and imported varieties of good  $j$ .

The problem of the firm consists of choosing the amount of inputs  $q_{jt}^d$  and  $q_{jt}^m$  to maximize profits. The prices of the domestic and imported varieties are given by  $p_{jt}^d$  and  $p_{jt}^m$ ,

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<sup>7</sup>We abstract from the impact on optimal policy of markup distortions induced by monopolistic competition. To do so, we let the government subsidize domestic sales with a proportional subsidy equal to  $\frac{1}{\sigma-1}$ , financed via lump-sum taxes levied on the owners of the respective producer; we omit this subsidy from the formulation above to simplify the exposition.

respectively. Imports are subject to iceberg trade costs  $\tau_j$  and import tariffs  $\tau_{jt}^m$  that are ad-valorem and such that  $\tau_j \geq 1$ .<sup>8</sup>

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

$$\begin{aligned} & \max_{y_{jt}, q_{jt}^d, q_{jt}^m} p_{jt} y_{jt} - p_{jt}^d q_{jt}^d - (1 + \tau_{jt}^m) \tau_j p_{jt}^m q_{jt}^m \\ & \text{subject to} \\ & y_{jt} = \left[ \omega_j q_{jt}^d \frac{\sigma-1}{\sigma} + (1 - \omega_j) q_{jt}^m \frac{\sigma-1}{\sigma} \right]^{\frac{\sigma}{\sigma-1}}. \end{aligned}$$

## 2.5 Producers of final goods

A representative firm produces final goods  $y_t$  combining essential  $e_t$  and non-essential  $n_t$  composite goods. To do so, the firm operates a constant elasticity of substitution technology given by:

$$y_t = \left[ (1 - \gamma) n_t^{\frac{\rho-1}{\rho}} + \gamma \left( \frac{e_t}{\bar{e}_t} \right)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}},$$

where the parameter  $\gamma$  controls the relative importance of the two goods for the aggregate absorption bundle,  $\rho$  denotes the elasticity of substitution between essential and non-essential goods, and  $\bar{e}_t$  refers to the “reference level” of essential goods relative to which absorption of these goods is evaluated. We model this reference level as exogenous and time-varying. Moreover, we capture the critical nature of essential goods by assuming that they are complementary with non-essential goods ( $\rho < 1$ ).

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

$$\begin{aligned} & \max_{y_t, n_t, e_t} p_t y_t - p_{nt} n_t - p_{et} e_t \\ & \text{subject to} \\ & y_t = \left[ (1 - \gamma) n_t^{\frac{\rho-1}{\rho}} + \gamma \left( \frac{e_t}{\bar{e}_t} \right)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}. \end{aligned}$$

The goal of this specification is to capture key dimensions along which essential goods might be different from non-essential goods. The contribution of essential goods to the production of final goods is a function of the ratio between  $e_t$  and a reference level  $\bar{e}_t$ .

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<sup>8</sup>Negative import tariffs denote import subsidies.

This captures that demand for some goods is often evaluated relative to the perceived need for them. Final goods may be interpreted as consisting of a bundle of consumption goods or, alternatively, as capturing an aggregate production technology with essential and non-essential inputs.

## 2.6 Government

Finally, the economy is populated by a government that collects revenue from the taxation of imports  $\{\tau_{jt}^m\}_{j \in \{n,e\}}$  and exports  $\{\tau_{jt}^m\}_{j \in \{n,e\}}$ , and which uses these revenues to subsidize domestic production  $\{\tau_{jt}^y\}_{j \in \{n,e\}}$  and to provide lump-sum transfers to households  $\{\mathcal{T}_{it}\}_{i \in \{n,e\}}$ . The government does not have access to financial markets, so its budget constraint has to be balanced every period. The government's budget constraint is given by:

$$\mathcal{T}_{nt} + \mathcal{T}_{et} = \sum_{j \in \{n,e\}} \left\{ \tau_{jt}^m \tau_j p_{jt}^m q_{jt}^m + \tau_{jt}^x p_{jt}^x y_{jt}^x - \tau_{jt}^y [p_{jt}^d y_{jt}^d + p_{jt}^x y_{jt}^x] \right\}.$$

Given a set of taxes and subsidies, there are multiple configurations of lump-sum transfers available to ensure the budget is balanced. To characterize the multiple arrangements available, we let  $\psi_{ijt}^k$  denote the share of revenue from policy  $k \in \{m, x, y\}$  on good  $j \in \{n, e\}$  in period  $t$  that is redistributed lump-sum to households of type  $i \in \{n, e\}$  — where  $k = m$  denotes import tariffs,  $k = x$  denotes export taxes, and  $k = y$  denotes sales subsidies. Then, transfers  $\{\mathcal{T}_{it}\}_{i \in \{n,e\}}$  need to satisfy:

$$\mathcal{T}_{it} + \sum_{j \in \{n,e\}} \psi_{ijt}^y \tau_{jt}^y (p_{jt}^d y_{jt}^d + p_{jt}^x y_{jt}^x) = \sum_{j \in \{n,e\}} \psi_{ijt}^x \tau_{jt}^x p_{jt}^x y_{jt}^x + \sum_{j \in \{n,e\}} \psi_{ijt}^m \tau_{jt}^m \tau_j p_{jt}^m q_{jt}^m,$$

where budget balance is ensured by  $\psi_{njt}^k + \psi_{ejt}^k = 1$ . We discuss our approach to specifying parameters  $\{\psi_{ijt}^k\}$  when investigating optimal policy design in Section 5.

## 2.7 Equilibrium

Consider a sequence of shocks  $\{\bar{e}_t, p_{jt}^x, p_{jt}^m\}_{t=0, j \in \{n,e\}}^\infty$ , a sequence of trade policy instruments  $\{\tau_{jt}^x, \tau_{jt}^m\}_{t=0, j \in \{n,e\}}^\infty$ , a sequence of industrial policy instruments  $\{\tau_{jt}^y\}_{t=0, j \in \{n,e\}}^\infty$ , and initial values  $\{b_{j0}, k_{j0}\}_{j \in \{n,e\}}$ . We let the price of the domestic variety of non-essential goods in the home country  $p_{nt}^d$  be our numeraire. Then, a *competitive equilibrium* consists of:

- wages  $\{w_t\}_{t=0}^\infty$ , prices  $p_t$  and  $\{p_{jt}, p_{jt}^d\}_{t=0, j \in \{n,e\}}^\infty$ ,

- allocations:

$$\left\{ c_{jt}, b_{jt+1}, \mathcal{T}_{jt}, \pi_{jt}, \ell_{jt}, k_{jt+1}, i_{jt}, y_{jt}, y_{jt}^d, y_{jt}^x, q_{jt}^d, q_{jt}^m, y_t, n_t, e_t \right\}_{t=0, j \in \{n, e\}}^{\infty},$$

such that the following conditions hold:

1. Given prices, allocations solve the problem of each household type
2. Given prices, allocations solve the problem of domestic producers of each type
3. Given prices, allocations solve the problem of composite goods producers of each type
4. Government's budget is balanced
5. Labor market clears:  $\ell_{nt} + \ell_{et} = \lambda_n + \lambda_e \forall t$
6. Domestic essential goods market clearing:  $y_{et}^d = q_{et}^d \forall t$
7. Domestic non-essential goods market clearing:  $y_{nt}^d = q_{nt}^d \forall t$
8. Essential composite goods market clearing:  $e_t = y_{et} \forall t$
9. Non-essential composite goods market clearing:

$$n_t + \sum_{j \in \{n, e\}} \left[ i_{jt} + \frac{\Omega_{kj}}{2} \left( \frac{k_{jt+1}}{k_{jt}} - 1 \right)^2 + \frac{\Omega_{\ell j}}{2} \left( \frac{\ell_{jt}}{\ell_{jt-1}} - 1 \right)^2 \right] = y_{nt} \forall t$$

10. Final goods market clearing:  $c_t = y_t \forall t$ .

### 3 Mechanism

In this section, we describe how we use our framework to study shortages of critical goods in a global economy, along with the key mechanisms at play. Our main experiment consists of an unexpected global increase in the demand for essential goods. Domestically, we study the impact of a transitory unexpected increase in the reference level  $\bar{e}_t$ , capturing increased domestic needs for these goods. We consider an analogous increase in the need for essential goods through an unexpected increase in the price of imports and exports of essential goods,  $p_{et}^m$  and  $p_{et}^x$ . While both essential and non-essential goods are modeled symmetrically, our interpretation of essential goods as critical is driven by the following two features: (i) essential

goods and the rest of the goods produced in the economy are complementary, (ii) there is a sudden and large increase in the need for these goods (due to either an increase in demand or a decline in supply).

In the rest of this section, we investigate how demand and supply of essential goods respond to the transitory increase in the need for these goods, giving rise to shortages.

### 3.1 Demand response

We first study the impact of the shocks described above on the demand for essential goods. The production technology of the final goods producer shows that the level of essential goods required to produce a given amount of final goods is now higher than prior to the shock. And, moreover, domestic and imported varieties of essential goods become more expensive due to higher export and import prices.

This increase in the reference level reduces the returns to final goods producers from purchasing a given amount of essential goods. And final goods producers are further discouraged to purchase these goods due to the increase in their prices. Producers of final goods are, thus, inclined to substitute essential goods with non-essential goods until the shock subsides. However, intra-temporal complementarities imply that final producers do not find it optimal to do so.

Specifically, producers of final goods operate a constant elasticity of substitution technology with essential and non-essential goods as inputs, where we consider the elasticity between them to be below unity. Thus, final goods producers do not find it optimal to respond to the increase in the reference level and prices by substituting consumption of essential goods with consumption of non-essentials. Instead, the increase in the reference level leads to an increase in the demand for essential goods:

$$\frac{e_t}{n_t} = \left( \frac{p_{et}}{p_{nt}} \right)^{-\rho} \left( \frac{\gamma}{1-\gamma} \right)^{\rho} \bar{e}_t^{1-\rho},$$

which shows that  $\bar{e}_t$  increases the ratio of essential to non-essential goods as long as  $\rho < 1$ . Higher prices of essential goods do reduce the demand for these goods, but these effects are relatively muted if complementarities are sufficiently strong.

In addition, the higher reference level and prices increase the price of final goods faced by households. These price changes encourage households to reduce consumption during this period in exchange for higher future consumption when the shocks subside. However, house-

holds have preferences represented through a constant relative risk aversion utility function, which features a finite intertemporal elasticity of substitution  $1/\xi < \infty$ . Then, consumption is not easily substitutable over time, making households prefer smooth consumption paths over non-smooth ones. As a result, households' demand for final goods during the period of the shock is not likely to be substantially affected.

The overall impact of the global shock is to increase the demand for essential goods despite the sharp increase in prices, as households and final goods producers have little room for intra- and inter-temporal substitution due to the presence of complementarities.

### 3.2 Supply response

Next, we study the impact of the shocks on the supply of essential goods. To study how firms adjust production after a large demand shock, it is instructive to examine these producers' first-order conditions for their choice of labor and capital<sup>9</sup>:

$$q_{et}^x \eta \alpha \ell_{et}^{\alpha \eta - 1} k_{et}^{\eta(1-\alpha)} + \mathbb{E}_t \left\{ m_{et} p_{nt+1} \frac{\partial \phi_{\ell et+1}}{\partial \ell_{et+1}} \right\} = w_{nt} + p_{nt} \frac{\partial \phi_{\ell et}}{\partial \ell_{et}},$$

$$\mathbb{E}_t \left\{ m_{et} \left[ q_{et+1}^x \eta (1-\alpha) \ell_{et+1}^{\alpha \eta} k_{et+1}^{\eta(1-\alpha)-1} + (1-\delta) p_{nt+1} + p_{nt+1} \frac{\partial \phi_{ket+1}}{\partial k_{et+2}} \right] \right\} = p_{nt} \left[ 1 + \frac{\partial \phi_{ket}}{\partial k_{et+1}} \right].$$

In both equations, the left-hand side captures the expected returns from a marginal increase in the production input. For labor, the returns arise from the extra output produced and from reduced future adjustment costs. For capital, the returns arise also from the value of the undepreciated amount of capital after production. The right-hand side of these equations captures the costs to be incurred today: wages, investment, and adjustment costs.

A key channel through which the global increase in the need for essential goods raises the supply of critical goods is by increasing the returns to production. In particular, higher export prices lead producers to increase both investment and labor. Two key factors control the degree to which these producers increase production. First, note that adjustment costs and the transitory nature of the shocks imply that firms may not increase production as much as they otherwise would. Second, note that the expected returns to increasing labor and capital inputs are mediated by the stochastic discount factor of the household that owns the producer of essential goods,  $m_{et}$ .

Given that households operate under incomplete financial markets, the bond-holding

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<sup>9</sup>To ease the exposition, we abstract here from export taxes and sales subsidies, setting them to zero.

costs imply that the stochastic discount factor of the owner of essential goods producers is affected by the investment increase following the shocks. To see this, note that the Euler equation of the households that own essential goods producers is given by:

$$\mathbb{E}_t m_{et+1} = \mathbb{E}_t \left[ \beta \frac{\partial u_i(n_{it+1}, e_{it+1}) / \partial e_{it+1}}{\partial u_i(n_{it}, e_{it}) / \partial e_{it}} \right] = \frac{1}{1+r} - p_n \Omega_b (b'_{et+1} - \bar{b}). \quad (1)$$

Thus, as households borrow to finance the production increase and to increase consumption due to the rise of permanent income, the bond-holding costs lead to a decline in the households' stochastic discount factor. These dynamics of the owners' stochastic discount factor ultimately mitigate the production increase. Thus, the economy features underinvestment and underhiring relative to an economy with better opportunities to pool financial resources with other households or the rest of the world.

### 3.3 Shortages of critical goods

We define shortages of essential goods as characterized by states of the world in which  $e < \bar{e}$ . This definition hinges on our interpretation of the reference level  $\bar{e}$  as capturing the needs for these goods. Thus, shortages arise when consumption  $e$  is below needs  $\bar{e}$ .

In our model, markets clear and demand and supply of essential goods is equalized in equilibrium. However, the large increase in  $\bar{e}$  does not result in a sufficiently large increase in consumption to meet the higher need for these goods. As a result, there are shortages of essential goods following the shock.

These shortages of essential goods result from the demand and supply responses discussed above. On the one hand, intra- and inter-temporal complementarities prevent final goods producers and households from substituting consumption of essential goods for non-essential goods or across time. As a result, demand for these goods increases substantially. On the other hand, adjustment costs imply that production of these goods takes time to scale up to meet the increased demand.

Shortages are exacerbated by the presence of incomplete markets and household heterogeneity, as captured in Equation (1). Given that borrowing is subject to bond-holding costs and that agents cannot pool resources between them, essential goods producers cannot borrow as much as they would otherwise without affecting their consumption patterns. This affects households' stochastic discount factor and, thus, firms' production decisions, leading to underproduction and inefficient outcomes — introducing a role for policy to mitigate



shortages of essential goods. In the next sections, we investigate the quantitative importance of these forces as well as the potential role for trade and industrial policies to mitigate some of these effects.

## 4 Quantitative analysis

To study the quantitative importance of the channels described in the previous section and the role for policy intervention, we focus on a specific application: shortages of essential medical goods during the outbreak of COVID-19. Specifically, the pandemic led to a massive increase in the demand for essential medical equipment and supplies (e.g., gowns, masks, gloves, intensive-care equipment, etc.) that have been critical to combat it and prevent the spread of the disease. While supply increased gradually in an attempt to satisfy the high demand for these goods, countries have faced supply shortages, forcing them to ration these goods and face exorbitant prices.

We begin by documenting salient features of the dynamics of demand, supply, and prices of essential medical goods during the COVID-19 pandemic. We then describe our approach to modeling the onset of a pandemic in our framework. We describe our estimation strategy to match salient features of the U.S. economy both prior to and during the COVID-19 pandemic. We conclude this section by studying the dynamics of the economy throughout this episode.

### 4.1 Essential medical goods during COVID-19 in the U.S.

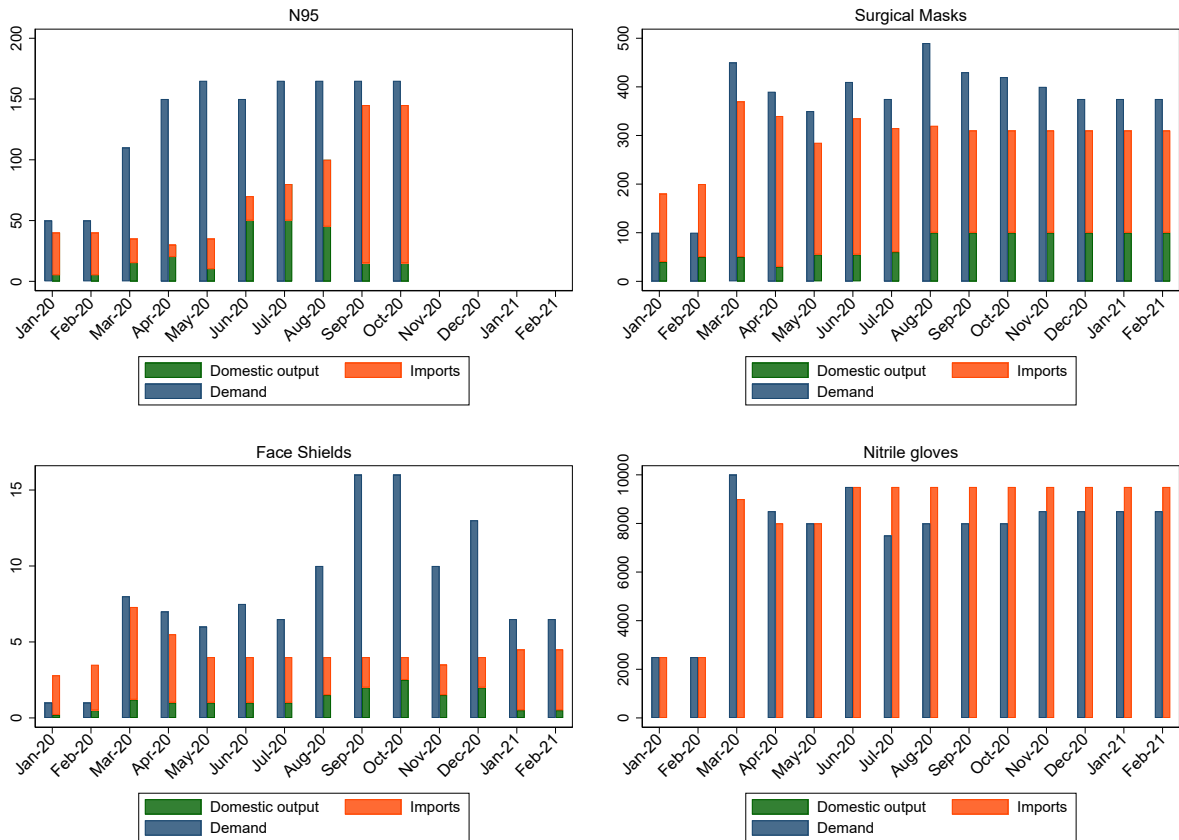
Given data limitations, we restrict attention to U.S. data on the following types of personal protective equipment (PPE): N95 respirators, surgical masks, gloves, and face shields. We interpret the evidence for these four types of goods as representative of the broader set of PPE required to prevent the spread of COVID-19. We obtain these data from the White House COVID-19 Supply Chain Task Force.<sup>10</sup>

**Demand vs. supply of personal protective equipment** We begin by documenting the evolution of demand and supply of PPE that has been critical to prevent the transmission of COVID-19. Our analysis is based on estimates of the demand and supply of these goods reported by the task force for Jan 2020 - Feb 2021, right before the introduction of COVID-19 vaccines. Figure 1 reports our findings, with blue bars representing PPE demand as

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<sup>10</sup>The projections were created by the White House Supply Chain Task Force, released by Democratic Sen. Maggie Hassan's office: <https://www.hassan.senate.gov/imo/media/doc/SCTF\%20Demand\%20PPE\%20Chart.pdf>

**Figure 1: PPE Demand and Supply in the U.S., Jan 2020 – Feb 2021**



Note: The  $y$ -axes are expressed in millions of units. All data are from the White House Supply Chain Task Force.

estimated by the Task Force, while the sum of the green (absorption of domestic goods) and red (absorption of imported goods) bars represent PPE supply available for consumption. Therefore, observations with blue bars (demand) higher than the red-green bars (supply) reflect shortages of the given product in the given period. We highlight three key facts.

First, we observe that PPE demand across these four types of goods experienced a significant increase between February and March 2020, at the onset of the pandemic, remaining high through February 2021. For instance, the estimated demand for N95 masks doubled between February and March, tripling by April; the demand for the rest of the goods increased even more sharply.

Second, changes in PPE supply were generally not sufficient to meet the increased demand for these goods. While domestic and imported consumption of all such goods increased during the pandemic, this increase was not sufficiently large to meet the spike in demand, leading

to shortages.

Finally, we observe that international trade is a critical source of PPE in the U.S. In particular, across all four types of goods, the average share of imports in total supply is higher than 70%. While nitrile gloves provide an extreme example, with virtually zero domestic production, domestic production plays a very minor role in the overall supply of all of these goods.

**Price changes of personal protective equipment** We now investigate the implications of these shortages of essential goods for their respective prices. To do so, we document the price changes across the four PPE categories identified by the White House COVID-19 Supply Chain Task Force. Data limitations prevent us from obtaining comprehensive information on the prices of PPE that were prevalent in the U.S. during the pandemic. Thus, we combine data from various sources.

For nitrile gloves, face shields, and surgical masks, we rely on international trade data from the United States International Trade Commission (USITC). In particular, we use monthly unit values of U.S. imports reported across disaggregate 10-digit HS product categories. First, we identify the set of 10-digit HS product codes corresponding to nitrile gloves, face shields, and surgical masks. For each 10-digit HS product and each month in 2020, we compute price changes relative to its respective average price in 2019. Then, for each broad product category under analysis, we compute the median price change across all 10-digit HS products that belong to such category.

Prices for N95 masks are not available in the USITC database before July 2020.<sup>11</sup> Thus, we obtain prices of N95 masks from a study conducted by The Society for Healthcare Organization Procurement Professionals (SHOPP) in April 2020.<sup>12</sup> The prices reported in the study are based on current market pricing and Centers for Disease Control and Prevention guidelines on PPE costs incurred by skilled nursing facilities and assisted living centers treating COVID-19 patients.

We report our findings in Table 1. We find that the price of PPE increased substantially during the pandemic, likely reflecting the severe supply shortages documented above. Rela-

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<sup>11</sup>The July 1<sup>st</sup>, 2020 Revision of the U.S. Harmonized Tariff Schedule introduced a dedicated product category to identify N95 masks: 6307.90.9845. Prior to this revision, N95 were included under subheading 6307.90.9889.

<sup>12</sup>See <https://shopp.org/> and [http://cdn.cnn.com/cnn/2020/images/04/16/shopp.covid.ppd.costs.analysis\\_.pdf](http://cdn.cnn.com/cnn/2020/images/04/16/shopp.covid.ppd.costs.analysis_.pdf).

**Table 1: PPE Prices**

Peak price change relative to 2019 average	
N95 respirators	1,513%
Surgical masks	104.8%
Face shields	21.01%
Nitrile gloves	95.35%

Note: For nitrile gloves, face shields, and surgical masks, the peak price change is computed using data from March to December 2020. For N95 masks, the peak price change is based on data for April 2020.

tive to the average prices throughout 2019, the peak increase in the price of N95 respirators was 1,513%, while the respective values for surgical masks and nitrile gloves was 104% and 95%, respectively. Face shields experienced the lowest price increase, equal to 21% at the peak relative to the 2019 average. These price changes are consistent with Bown (2021).<sup>13</sup>

## 4.2 A pandemic in the model

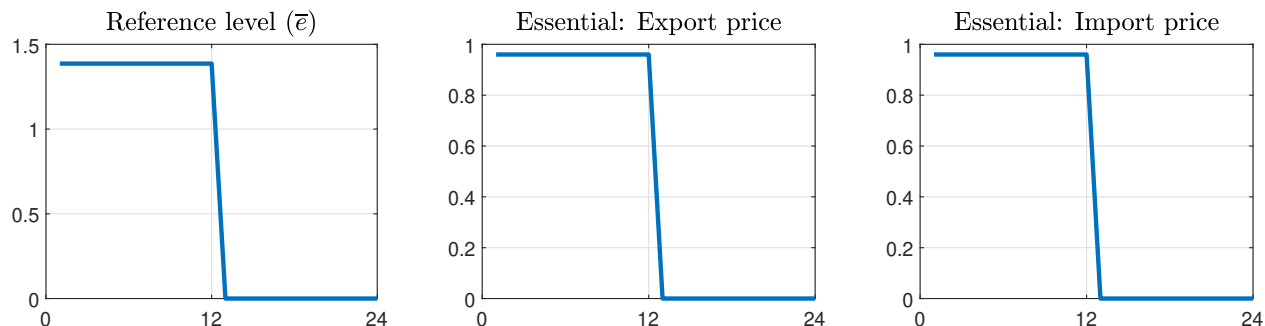
Motivated by this evidence, we model a global pandemic as the combination of domestic and foreign shocks. Domestically, the economy experiences a shock that increases the reference level of essential goods  $\bar{e}$ . This captures the increased need for PPE throughout COVID-19. On the foreign front, the economy experiences shocks to the price of imports and exports of essential goods. As documented above and reported throughout, the pandemic increased global demand for essential goods, which led to higher prices and rationing of essential goods. We model these effects as captured by shocks to  $q_e^x$  and  $q_e^m$ .<sup>14</sup>

Given the high frequency dynamics of the pandemic, we interpret a period in the model as a month in the data. Given our focus on shortages of essential medical goods prior to the development of vaccines, we study a pandemic that lasts for 12 months. We let period 0 denote the initial steady state. The full path of shocks is observed in period 1. Agents observe that the pandemic raises  $\bar{e}$ ,  $q_e^x$ , and  $q_e^m$  for 12 periods, with their values reverting back to their initial steady-state levels in period 13 — we study the perfect foresight solution of the model in response to these shocks. To simplify the analysis, we assume that each shocked parameter increases once and for all until the end of the pandemic.

<sup>13</sup>See Cabral and Xu (2021) for a detailed analysis of the role of price gouging on observed price changes.

<sup>14</sup>To simplify the analysis, we assume that import and export prices increase by the same amount.

**Figure 2: A global pandemic**



Note: The  $x$ -axes denote time periods. The  $y$ -axes are expressed as log deviations from steady-state.

Given data limitations, we parameterize the shocks by restricting attention to the four essential medical goods identified by the White House COVID-19 Supply Chain Task Force and described in detail in Section 4.1: N95 masks, surgical masks, face shields, and nitrile gloves. We set the shock to the reference level  $\bar{e}$  to match the increased demand for these goods documented in Figure 1. For each good, we first identify the peak demand over this period relative to pre-pandemic demand and then compute the median across goods. The demand for the median good increases by 1.39 log-points at the peak. Thus, we consider an increase of  $\bar{e}$  such that  $\Delta \ln \bar{e} = 1.39$  throughout the 12 months of the pandemic. Figure 2 plots the dynamics of the shocks that characterize a pandemic in our model.

We set the shocks to import and export prices to match changes in the unit values of essential COVID-19 goods from the USITC and the World Customs Organization. First, we identify the set of product codes corresponding to goods identified as essential, as described above.<sup>15</sup> For each good we identify the highest price change relative to pre-pandemic prices, and then compute the median across goods. We find the price of the median good increased by 0.96 log-points at the peak. Thus, we consider an increase of import and export prices such that  $\Delta \ln q_e^x = \Delta \ln q_e^m = 0.96$  during the 12 months of the pandemic.

### 4.3 Parameterization

To parametrize the model, we partition the parameter space into three sets of parameters: predetermined parameters, parameters estimated to match moments of the U.S. economy prior to the onset of COVID-19, and parameters estimated to match the dynamics of the

<sup>15</sup>We restrict attention to product codes with non-missing data throughout the first 12 months of the pandemic.

**Table 2: Predetermined parameters**

Parameter	Value	Description
$\beta$	$0.96^{\frac{1}{12}}$	Discount factor
$1/\xi$	0.50	Intertemporal elasticity of substitution
$\sigma$	4	Armington elasticity
$\alpha$	0.66	Labor share
$\eta$	0.85	Returns to scale
$\delta$	0.01	Capital depreciation rate
$\omega_e = \omega_c$	0.50	Weight on home goods
$A_e$	1	Productivity of essential goods sector

U.S. economy following COVID-19.

**Predetermined parameters** Predetermined parameters are set to standard values from the literature and consist of the discount factor  $\beta$ , the intertemporal elasticity of substitution  $1/\xi$ , the elasticity of substitution between domestic and imported varieties of essential and non-essential goods  $\sigma$ , the labor share  $\alpha$ , the degree of returns to scale  $\eta$ , and the capital depreciation rate  $\delta$ . We normalize weights  $\omega_e$  and  $\omega_c$  to  $1/2$ , and the productivity of essential goods producers to 1.

Table 2 reports the parameter values used throughout. We set  $\beta$  to  $0.96^{\frac{1}{12}}$ , which implies an annual interest rate of 4%. We set the intertemporal elasticity of substitution  $1/\xi$  to 0.50 ( $\xi = 2$ ), which is consistent with empirical estimates using aggregate data (Hall 1988; Campbell and Mankiw 1989). The elasticity of substitution  $\sigma$  is set to 4 following Simonovska and Waugh (2014), implying that domestic and imported varieties are relatively substitutable. We set the labor share  $\alpha$  to  $2/3$  and returns to scale  $\eta$  to 0.85 following Midrigan and Xu (2014) and Atkeson and Kehoe (2007). We set the monthly depreciation rate  $\delta$  to 1%, implying an annual depreciation rate  $\approx 11\%$ , consistent with equipment depreciation estimates in U.S. manufactures (Albonico, Kalyvitis, and Pappa 2014).

**Parameters estimated to match targets prior to COVID-19** The set of parameters estimated to match moments of the U.S. economy prior to COVID-19 consists of the productivity of non-essential goods producers  $A_n$ , the iceberg trade costs  $\tau_e$  and  $\tau_n$ , the reference level of essential goods  $\bar{e}$  in the steady state, the weight  $\gamma$  of essential goods in the technol-

ogy of final goods producers, the measures  $\lambda_n$  and  $\lambda_e$  of households of each type, and the steady-state levels of debt  $\bar{b}_n$  and  $\bar{b}_e$  held by households of each type.

Before describing the estimation targets, we make two normalizations. First, we assume that there is a unit mass of households in the economy. Thus, given a value of  $\lambda_n \in (0, 1)$ , we have  $\lambda_e = 1 - \lambda_n$ . Second, we assume that the distribution of steady-state debt-holdings across agents is proportional to their relative mass. Thus, given a value of debt  $\bar{b}_n$  held by agent  $n$  in steady-state, we have  $\bar{b}_e = \lambda_e (\bar{b}_n + \bar{b}_e)$  — that is,  $\bar{b}_e = \frac{\lambda_e}{1 - \lambda_e} \bar{b}_n$ .

Then, we choose the remaining seven parameters to ensure that the steady state of our model captures the following features of the U.S. economy prior to the onset of COVID-19: *(i)* the net exports-to-GDP ratio in essential goods, *(ii)* the share of essential goods in aggregate GDP, *(iii)* the share of essential goods absorption that is imported, *(iv)* the share of non-essential goods absorption that is imported, *(v)* the aggregate net exports-to-GDP ratio, *(vi)* the aggregate absorption of essential goods relative to their reference level, and *(vii)* the share of aggregate labor supplied by households of type  $n$ .

To compute empirical counterparts to these moments, we begin by classifying goods into essential and non-essential. Limited data availability prior to COVID-19 prevents us from restricting attention solely to PPE that was key at the onset of COVID-19.<sup>16</sup> Thus, we define essential goods as consisting of a broader range of medical goods: *(i)* medical equipment and supplies manufacturing and *(ii)* pharmaceutical and medicine manufacturing. Non-essential goods are defined as consisting of all other goods produced in the U.S.<sup>17</sup> We compute all moments using data from the Bureau of Economic Analysis and the U.S. Census.<sup>18</sup> Finally, given data limitations, we set the target values of moments *(vi)* and *(vii)* as follows: First, we assume aggregate consumption of essential goods is equal to the reference level in the pre-pandemic steady-state— $e = \bar{e}$ . Second, we assume that the share of aggregate labor supplied by households of type  $n$  is equal to the share of aggregate output accounted by the firms owned by such households.

The estimated parameters as well as the empirical targets and their model counterparts are reported in Table 3. We find that the seven estimated parameters can be chosen to match the seven targets exactly. To be a net importer of essential goods, the model requires

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<sup>16</sup>The key constraint that we face is that the product-level gross output data are not sufficiently disaggregated to distinguish between personal protective equipment and other medical goods.

<sup>17</sup>Thus, our empirical counterpart to GDP in the model is U.S. goods GDP.

<sup>18</sup>International trade data from U.S. Census consist of product-level data at the HS-6-digit level of disaggregation. There are a total of 5,402 product categories, from which 92 belong to the medical sector.

**Table 3: Estimated parameters, pre-pandemic steady-state**

Parameter	Value	Description
$A_n$	1.591	Sectoral productivity
$\tau_e$	0.138	Trade costs on essential goods
$\tau_n$	0.342	Trade costs on non-essential goods
$\bar{e}$	0.326	Reference level of essential goods
$\gamma$	0.001	Utility weight on essential goods
$\lambda_n$	0.957	Measure of agents of type $n$
$\bar{b}_n$	-147.89	Steady-state level of debt: Agent $n$
$\lambda_e$	$1 - \lambda_n$	Measure of agents of type $e$
$\bar{b}_e$	$\lambda_e (\bar{b}_n + \bar{b}_e)$	Steady-state level of debt: Agent $e$
Moment	Target value	Model
$NX_e/GDP_e$	-0.188	-0.188
$GDP_e/GDP$	0.043	0.043
$M_e/p_e e$	0.404	0.404
$M_n/p_n n$	0.293	0.293
$NX/GDP$	-0.063	-0.063
Aggregate $e/\bar{e}$	1.000	1.000
HH $n$ labor share	0.957	0.957

producers of non-essential goods to be more productive than producers 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. Trade costs determine the extent to which absorption of essential and non-essential goods is imported. And, finally, the aggregate net exports-to-GDP ratio is determined by the steady-state level of debt.

**Parameters estimated to match dynamics following COVID-19** Given our approach to modeling the pandemic, we estimate the remaining parameters to match salient features of the dynamics of the U.S. economy following the onset of COVID-19: the elasticity of substitution  $\rho$  between essential and non-essential goods, the capital and labor adjustment costs  $\{\Omega_{k,e}, \Omega_{\ell,e}\}$  faced by producers of essential goods, the capital and labor adjustment costs  $\{\Omega_{k,n}, \Omega_{\ell,n}\}$  faced by producers of non-essential goods, and the bond-holding costs  $\Omega_b$ . Given



data limitations, we simplify the estimation by assuming that  $\Omega_{k,e} = \Omega_{\ell,e}$  and  $\Omega_{k,n} = \Omega_{\ell,n}$ .

We choose the four estimated parameters to match the following features of the U.S. economy after the onset of COVID-19 relative to pre-pandemic levels: (i) the growth of essential goods consumption, (ii) the growth of absorption of non-essential goods, (iii) the growth of output of non-essential goods, and (iv) the change of net exports to GDP ratio. All moments are computed as the average monthly change throughout Q2 and Q3 of 2020 relative to Q4 of 2019.<sup>19</sup>

We compute empirical counterparts for these moments as follows: We compute moment (i) using estimates of domestic sales and imports of four critical goods from the White House COVID-19 Supply Chain Task Force, as described in Section 4.1. We first compute the median growth across goods for each month and then average across months. We use data on U.S. goods GDP from the BEA to measure consumption and output of non-essential goods, as well as the net exports-to-GDP ratio.

We estimate the parameters through a simulated method of moments (SMM) algorithm, designed to minimize the sum of absolute deviations between the empirical moments and their model counterparts, assigning equal weight to each of the moments.<sup>20</sup> Table 4 reports the estimated parameters as well as the empirical targets and their model counterparts. All moments are matched almost exactly except for the growth of essential goods consumption. We find that essential and non-essential goods are estimated to be complementary, with an elasticity of substitution equal to 0.269. We estimate positive sectoral adjustment costs in both sectors, with larger costs faced by producers of non-essential goods. And, finally, we estimate bond-holding costs equal to 0.024.

#### 4.4 Dynamics following shortages of essential goods

We now study the impact of a pandemic by computing impulse response functions following the shocks presented in Figure 2. The dynamics of key variables, expressed as percent deviations from their steady-state values, are presented in Figures 3 and 4.<sup>21</sup> We restrict attention to the dynamics over the first two years (24 periods) following the onset of the pandemic.

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<sup>19</sup>The only exception is moment (i), which is computed relative to January 2020 due to data availability.

<sup>20</sup>We study the perfect foresight solution of the model numerically using global methods.

<sup>21</sup>We report the dynamics of a broader set of variables in the Online Appendix.

**Table 4: Estimated parameters, pandemic dynamics**

Parameter	Value	Description	
$\rho$	0.269	Elasticity essential and non-essential	
$\Omega_{k,c} = \Omega_{n,c}$	46.087	Adjustment costs: Non-essential	
$\Omega_{k,e} = \Omega_{n,e}$	4.201	Adjustment costs: Essential	
$\Omega_b$	0.024	Bond-holding cost	
	Moment	Target value	Model
$e_t$	$\log(\text{Avg. Q2-Q3 '20} / \text{Pre-pandemic})$	0.619	0.663
$c_t$	$\log(\text{Avg. Q2-Q3 '20} / \text{Pre-pandemic})$	-0.062	-0.062
$y_{c,t}$	$\log(\text{Avg. Q2-Q3 '20} / \text{Pre-pandemic})$	-0.070	-0.070
$NX/GDP$	$\text{Avg. Q2-Q3 '20} - \text{Pre-pandemic}$	-0.009	-0.009

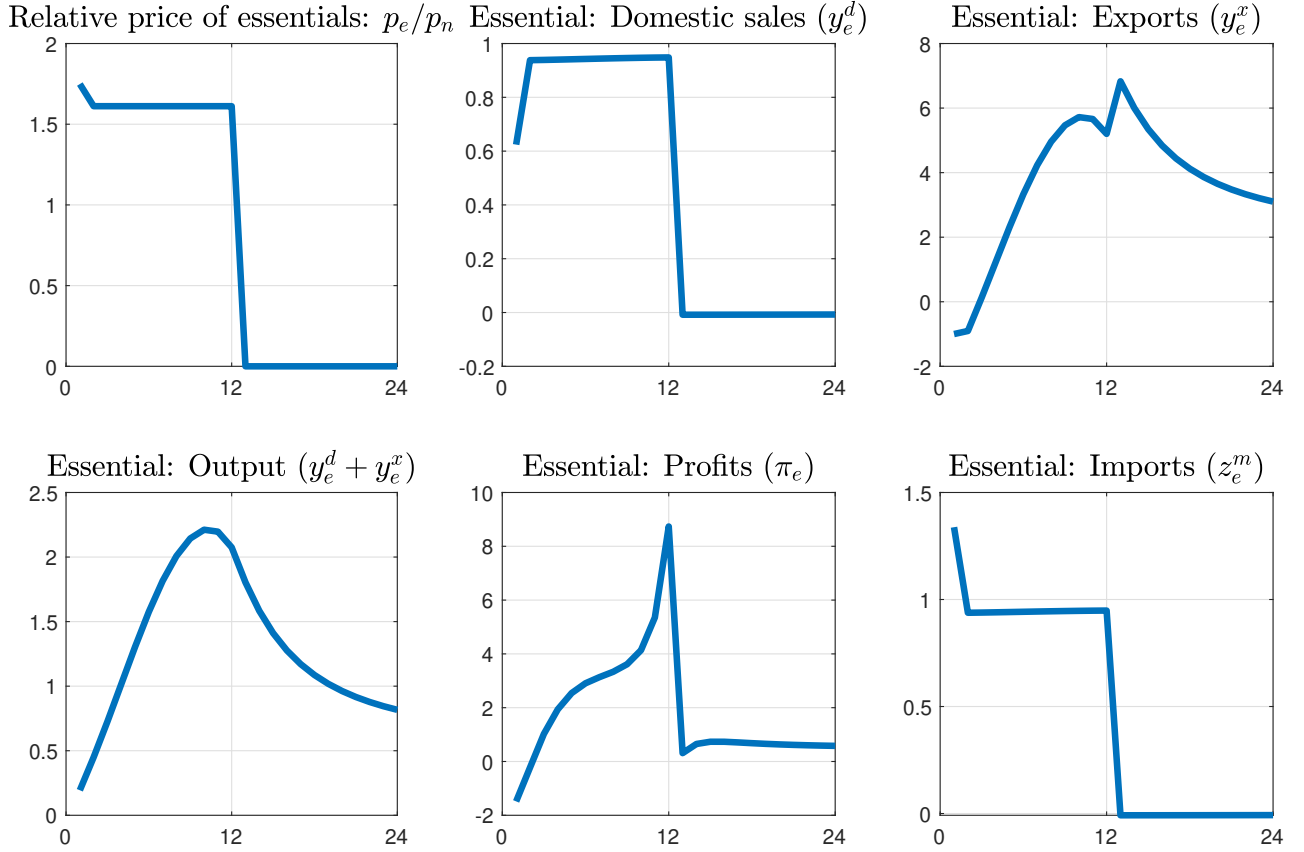
**Production and trade of essential goods** We begin with the dynamics of production and trade of essential goods, illustrated in Figure 3. Our starting point is that the higher export and import prices of essential goods significantly increase the overall price of essential goods. This is partially driven by the nontrivial fraction of essential goods that are imported. But, moreover, this is also accounted by the rise of export prices, which leads producers of essential goods to increase the domestic price of domestically produced essential goods.

These higher prices of essential goods increase the returns to accumulating capital and hiring labor, rising the optimal production scale. However, the production scale increases gradually given the costs to adjust capital and labor. This adjustment of the production scale involves short-run losses financed via equity injections from the households that own these producers — the losses are more than offset by increased profits thereafter.

The increased production of essential goods is distributed across all destination markets: Both domestic sales and exports of these goods increase. On the one hand, and despite sizable price increases, domestic demand for essential goods increases given the higher reference level along with the complementarity between essential and non-essential goods. Thus, both domestic sales and imports increase significantly throughout the pandemic. On the other hand, exports increase given the attractiveness of the higher export price along with the perfectly elastic demand faced by domestic producers when selling internationally.

Interestingly, we find that exports increase relatively more than domestic sales. Thus,

**Figure 3: Dynamics following a pandemic - Production and trade of essentials**



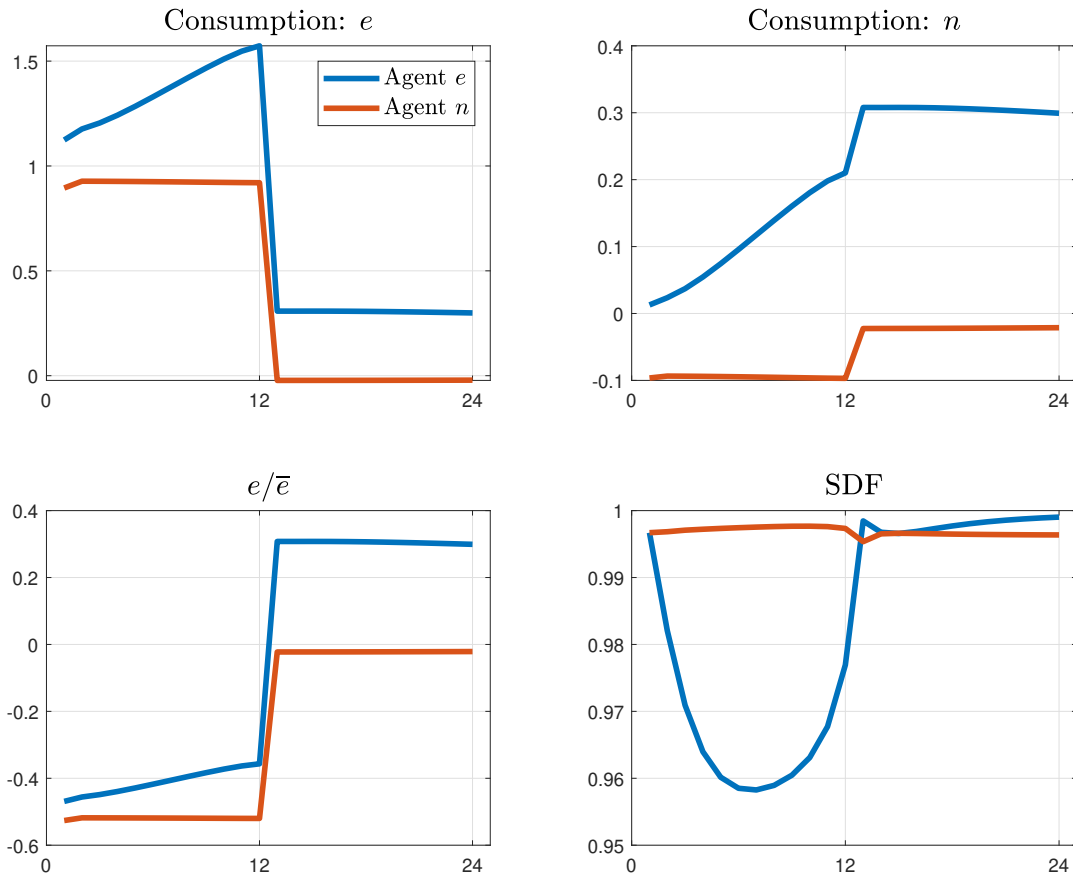
Note: The  $x$ -axes denote time periods (months). The  $y$ -axes are expressed as percent deviations from steady-state. Specifically, percent changes are obtained by multiplying the values in the panel by 100.

despite the higher domestic need and demand for essential goods, most of the increased production scale is actually exported rather than sold domestically. This implication raises questions about the desirability of the equilibrium outcomes. Is it socially optimal to increase exports of essential goods more than domestic sales at a time of increased need for these goods? We study these and other related questions in Section 5.

**Consumption and discounting** Given our setup with heterogeneous households and incomplete markets, the consumption and discounting dynamics implied by the model differ between them. Figure 4 plots key variables on the dynamics of consumption and discounting for households of both type  $n$  and  $e$ .

The consumption dynamics are qualitatively similar across households along some dimensions. For instance, both households increase the consumption of essential goods sharply throughout the pandemic. However, the consumption of these goods remains well below its

**Figure 4: Dynamics following a pandemic - Consumption and discounting**



Note: The  $x$ -axes denote time periods (months). The  $y$ -axes are expressed as percent deviations from steady-state, except for the SDF which is in levels. Specifically, percent changes are obtained by multiplying the values in the panel by 100.

reference level by the end of the pandemic.

Yet, the dynamics differ markedly across households along other dimensions. For instance, households of type  $e$  increase their consumption of both essential and non-essential goods, while households of type  $n$  increase their consumption of essential goods but reduce their non-essential consumption. Households that own producers of essential goods are relatively better off than the rest: They own the firms that produce the goods whose demand and prices have increased.

Moreover, the consumption dynamics also differ markedly across households along other dimensions: Households of type  $e$  increase consumption gradually, while households of type  $n$  do not exhibit significant dynamics after the initial adjustment. This difference in consumption dynamics is accounted for by the time-varying profits earned by households of

type  $e$ , with large initial losses and large returns toward the end of the pandemic. Financial market imperfections prevent these households from borrowing enough to fully smooth this income pattern, leading them to opt for smooth-but-increasing consumption paths.

The heterogeneous path followed by the consumption (and borrowing) dynamics across households is mirrored by the dynamics of each household's SDF. On the one hand, the SDF of households of type  $n$  remains relatively unchanged, reflecting their relatively flat pattern of consumption and borrowing throughout the pandemic. On the other hand, the SDF of households of type  $e$  declines significantly below its steady-state level throughout the pandemic. These households increase consumption gradually through increased borrowing, which raises the borrowing costs and implies a lower SDF.

These differences in discounting across households are also critical to determine the investment and hiring decisions of the firms that they own. In particular, the lower SDF of households of type  $e$  imply that producers of essential goods make investment and hiring decisions assigning relatively lower value to future returns. This implication raises questions about the desirability of the equilibrium outcomes. To what extent are the implied production decisions socially optimal? Is there a role for policy interventions that increase welfare? We study these and other related questions in the next section.

## 5 Optimal trade and industrial policy during a pandemic

We now investigate the extent to which the dynamics implied by the model following a pandemic are indeed welfare-maximizing, or whether there is a role for government policy to increase consumption of essential goods. In particular, we focus on two alternative types of policies: trade policies designed to alter the incentives of whether to sell and source essential goods domestically or internationally, and industrial policies designed to alter the incentives to produce essential goods. We ask: To what extent would it be optimal to introduce international trade or industrial policies on essential goods during a pandemic?

To answer this question, we endow the government with three policy instruments that apply only to essential goods: (i) ad-valorem import tariffs  $\tau_{et}^m$ , (ii) ad-valorem export taxes  $\tau_{et}^x$ , and (iii) ad-valorem sales subsidies  $\tau_{et}^y$ .<sup>22</sup> Note that negative values of  $\tau_{et}^m$  and  $\tau_{et}^x$  denote subsidies, while negative values of  $\tau_{et}^y$  denote taxes. We refer to (i) and (ii) as trade policies, and to (iii) as industrial policy. To simplify the analysis, we restrict attention to one-time transitory changes to (i) – (iii) that remain active throughout the duration of the pandemic,

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<sup>22</sup>We keep  $\tau_{nt}^m = \tau_{nt}^x = \tau_{nt}^y = 0$  throughout.

reverting back to zero (i.e., their steady-state values) after the pandemic ends in period 13.

As described in Section 2.6, we assume the government's budget constraint is balanced every period. Yet, our setup allows for multiple ways to allocate the financing and reimbursement of these policy instruments across households. We focus on a case that allows us to abstract from standard redistributive motives for policy interventions while, instead, studying the role for policy interventions that increase social welfare. In particular, we assume that (i) revenues from import tariffs on essential goods are rebated back to households in proportion to their consumption share of these goods (that is,  $\psi_{iet}^m = q_{it}^m / \sum_k q_{kt}^m$ ), (ii) revenues from export taxes on essential goods are rebated back to households that own essential goods producers (that is,  $\psi_{eet}^x = 1$  and  $\psi_{net}^x = 0$ ), (iii) subsidies on the production of essential goods are financed by households that own essential goods producers (that is,  $\psi_{eet}^y = 1$  and  $\psi_{net}^y = 0$ ).

Finally, we assume the government's objective function in period  $t$  consists of the weighted average between the value functions  $V_{nt}$  and  $V_{et}$  of households  $n$  and  $e$ , respectively, from period  $t$  onward. That is, the government's objective is given by:

$$\mathcal{V}_t = \mu_n V_{nt} + \mu_e V_{et},$$

where  $\mu_n$  and  $\mu_e$  denote the respective weights on each household's value function.

Then, the government's problem consists of choosing policies  $(\tau_e^m, \tau_e^x, \tau_e^y)$  throughout the pandemic to maximize its objective function starting from the period in which the shocks are first realized (period 1). Formally, the problem is given by:

$$\max_{\tau_e^m, \tau_e^x, \tau_e^y} \mathcal{V}_1(\tau_e^m, \tau_e^x, \tau_e^y), \quad (2)$$

where  $\mathcal{V}_1(\tau_e^m, \tau_e^x, \tau_e^y)$  denotes the government's objective function in period 1 in a competitive equilibrium with policies  $(\tau_e^m, \tau_e^x, \tau_e^y)$  implemented throughout the duration of the pandemic.

We choose welfare weights  $\mu_n$  and  $\mu_e$  such that there is no role for policy interventions in the pre-pandemic steady-state. To do so, we normalize  $\mu_n = 1$  and set  $\mu_e$  to equal the steady-state marginal utility to increasing essential goods consumption of household  $e$  relative to household  $n$ .<sup>23</sup>

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<sup>23</sup>Specifically, we set  $\mu_e = \frac{c_e^{-\xi} c_e^{1/\rho} \gamma \bar{e}^{(1-\rho)/\rho} e_e^{-1/\rho}}{c_n^{-\xi} c_n^{1/\rho} \gamma \bar{e}^{(1-\rho)/\rho} e_n^{-1/\rho}}$ .

## 5.1 Optimal policies

We solve the government’s problem described above under three alternative sets of policy instruments: (i) only trade policy, (ii) only industrial policy, and (iii) both trade and industrial policy.<sup>24</sup> Table 5 reports the optimal policy rates for each of these cases.<sup>25</sup>

The first row shows that, when restricted to trade policy instruments, the government finds it optimal to introduce a 14.26% tax on exports of essential goods throughout the pandemic, along with a 9.44% subsidy on imports of these goods.<sup>26</sup> That is, the government finds it optimal to simultaneously restrict exports of essential goods while increasing incentives to purchase imported varieties of these goods.

The second row shows that industrial policies are also effective at mitigating the impact of the pandemic. In particular, the government finds it optimal to encourage production of essential goods by subsidizing total sales with a 12.23% ad-valorem subsidy.

These findings show that both trade and industrial policies can be effective instruments throughout a pandemic to increase the production and consumption of essential goods. We now examine the potential to jointly introduce trade and industrial policies throughout a pandemic. The third row of Table 5 shows that, indeed, it is optimal to do so. In particular, the government finds it optimal to introduce a 25.02% export tax, an 18.28% import subsidy, and a 27.97% total sales subsidy. Our findings suggest that trade and industrial policies are complementary instruments: The optimal trade and industrial policy are larger when introduced jointly.<sup>27</sup> In the Online Appendix we show that these findings are robust under a number of alternative specifications of the model and quantification approach.

Our findings raise numerous questions on the impact of these policies and the channels that account for the optimal policy response during a pandemic. We address these questions in two ways. First, we investigate the impact of these optimal policies on welfare and the dynamics following a pandemic. Second, we investigate the role played by various features of the model in accounting for our findings.

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<sup>24</sup>To solve the government’s problem under policies (i) and (ii), we adjust the problem in Equation 2 accordingly. For (i), we solve it constraining  $\tau_e^y = 0$ . For (ii), we solve it constraining  $\tau_e^m = \tau_e^x = 0$ .

<sup>25</sup>The policies that solve the government’s problem are optimal subject to the instruments with which we endow the government. While they may be welfare-improving, they need not achieve the first-best allocations or solve the government’s problem under a broader set of instruments.

<sup>26</sup>In the Online Appendix we report the optimal policies when the government is endowed with only one trade policy instrument at a time.

<sup>27</sup>In the Online Appendix, we report the optimal policies in response to each of the shocks one at a time.

**Table 5: Optimal policies following a pandemic**

	Export tax	Import tariff	Total sales subsidy	Welfare gain
Trade policy	14.26%	-9.44%	—	0.011%
Industrial policy	—	—	12.23%	0.004%
Trade and industrial policy	25.02%	-18.28%	27.97%	0.033%

## 5.2 Welfare gains from optimal policies

We now investigate the welfare implications of the optimal trade and industrial policy interventions. This allows us to compare the relative gains from introducing the alternative sets of policies under consideration throughout a pandemic. For each alternative policy, we compute the welfare gains in consumption-equivalent units between an economy without policy interventions vs. an economy with optimal policy changes. Specifically, we ask: What uniform and permanent percentage increase of the consumption bundle of every household would make them indifferent from the lens of the government’s objective function between an economy with vs. without optimal policy changes throughout a pandemic?

To answer this question, we solve for the value of  $\alpha$  that equates (i) the value of the government’s objective function in period 1 without optimal policies but with household consumption, evaluated according to period utility  $\frac{[(1+\alpha)c]^{1-\xi}}{1-\xi}$ , with (ii) the value of the government’s objective function in period 1 under the optimal policies. Thus, while the policies are introduced throughout only 12 periods, the welfare gains are measured based on a permanent lifetime proportional increase of consumption. The last column of Table 5 reports our findings for the alternative sets of policy instruments that we consider.

We find that the welfare gains from optimal trade policy interventions on essential goods during a pandemic are equal to 0.011% in consumption-equivalent units. That is, households in an economy without policy changes would need their consumption bundle to increase by 0.011% every period forever to remain indifferent to living in the economy that implements the optimal trade policies during the pandemic. The gains are quantitatively significant: They are the same order of magnitude as the welfare cost of business cycles despite arising from policies that are introduced for only the duration of the pandemic (Lucas, 1987).

The computation of the welfare gains also allows us to contrast the relative effectiveness



of the alternative policies. The second row of the table shows that the welfare gains from industrial policies are significantly lower than those from the trade policies: 0.004% vs. 0.011%, respectively. Moreover, we find further evidence in support of the complementarity between trade and industrial policies: The welfare gain from these policies is equal to 0.033%, which is greater than the combined gains from introducing each of these policies in isolation.

### 5.3 Dynamics under optimal policies

Next, we investigate the impact of the optimal policies on the dynamics following a pandemic. To do so, we contrast the impulse response functions for key variables of the model with vs. without the optimal policy interventions.

**Optimal trade policy** We begin with the impact of the optimal trade policy interventions, presented in Figure 5. We find that the optimal trade policy allows most households to increase their consumption of essential goods relative to the economy without trade policy changes. Specifically, households of type  $n$ , which make up most of the households in the economy, increase their consumption of these goods relative to the reference level, while households of type  $e$  mildly reduce their consumption. Notice that consumption of these goods remains substantially below the reference level even under the optimal trade policy.

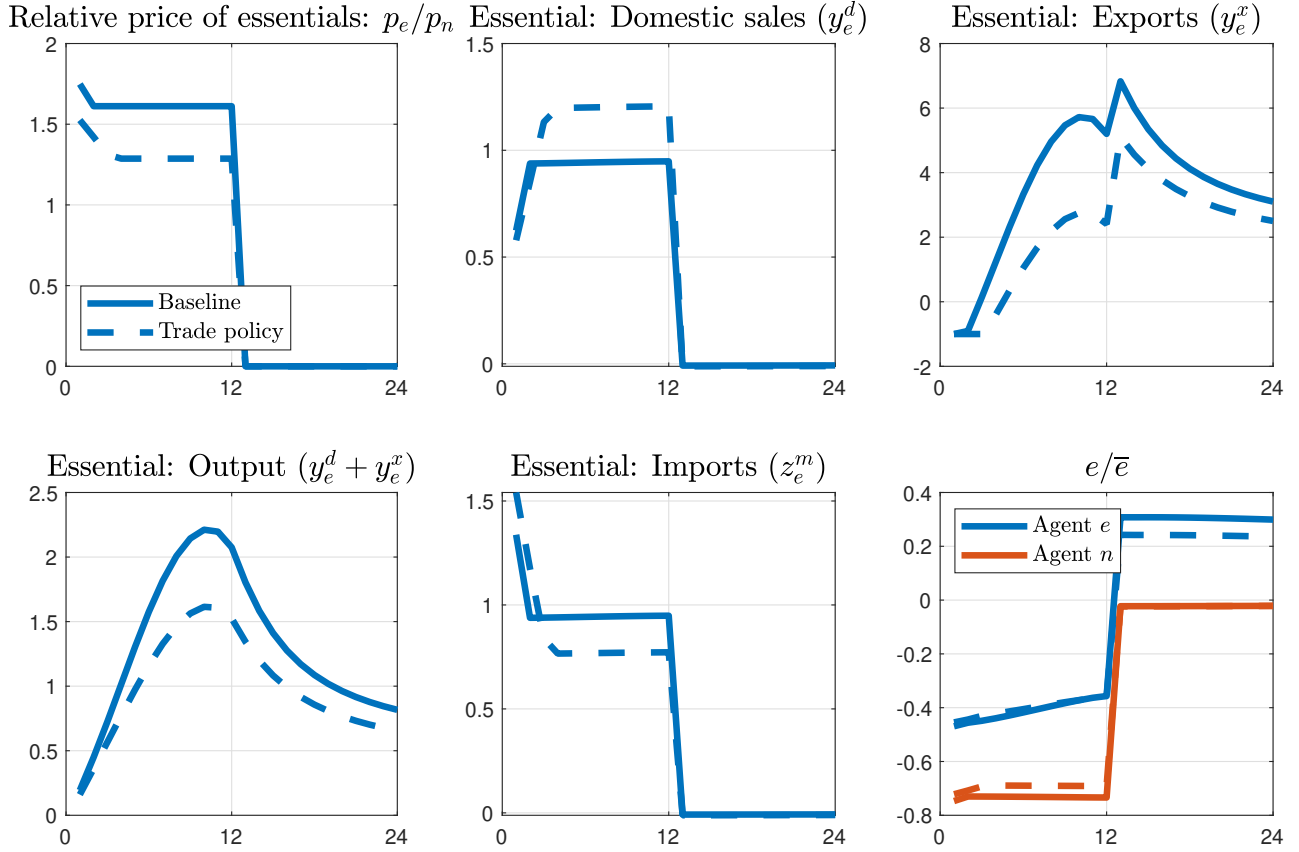
The tax on exports leads firms to lower the domestic price of essential goods. While this discourages production of essential goods, slowing down the increase of output, it leads to a reallocation of sales from exports to domestic consumers. Thus, domestic sales increase relatively more than under the baseline, while exports decline substantially. Thus, optimal export taxes result from balancing two conflicting forces: They reduce the incentives to produce essential goods, which are much needed during the pandemic, but they also increase domestic access to such goods.

The lower price of domestic varieties due to the export tax also leads to a reallocation of consumption of essential goods from imported to domestic varieties. The government finds it optimal to offset this reallocation of consumption by introducing an import subsidy.<sup>28</sup> This allows households to purchase imports of essential goods at a lower price, increasing imports of these goods. Thus, we find that both export taxes and import subsidies increase domestic and imported consumption of essential goods, mitigating the negative impact of the pandemic due to the increase in the reference level  $\bar{e}$ .

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<sup>28</sup>In the Online Appendix, we show that there is no role for import subsidies when introduced in isolation.

**Figure 5: Pandemic dynamics under optimal trade policy**

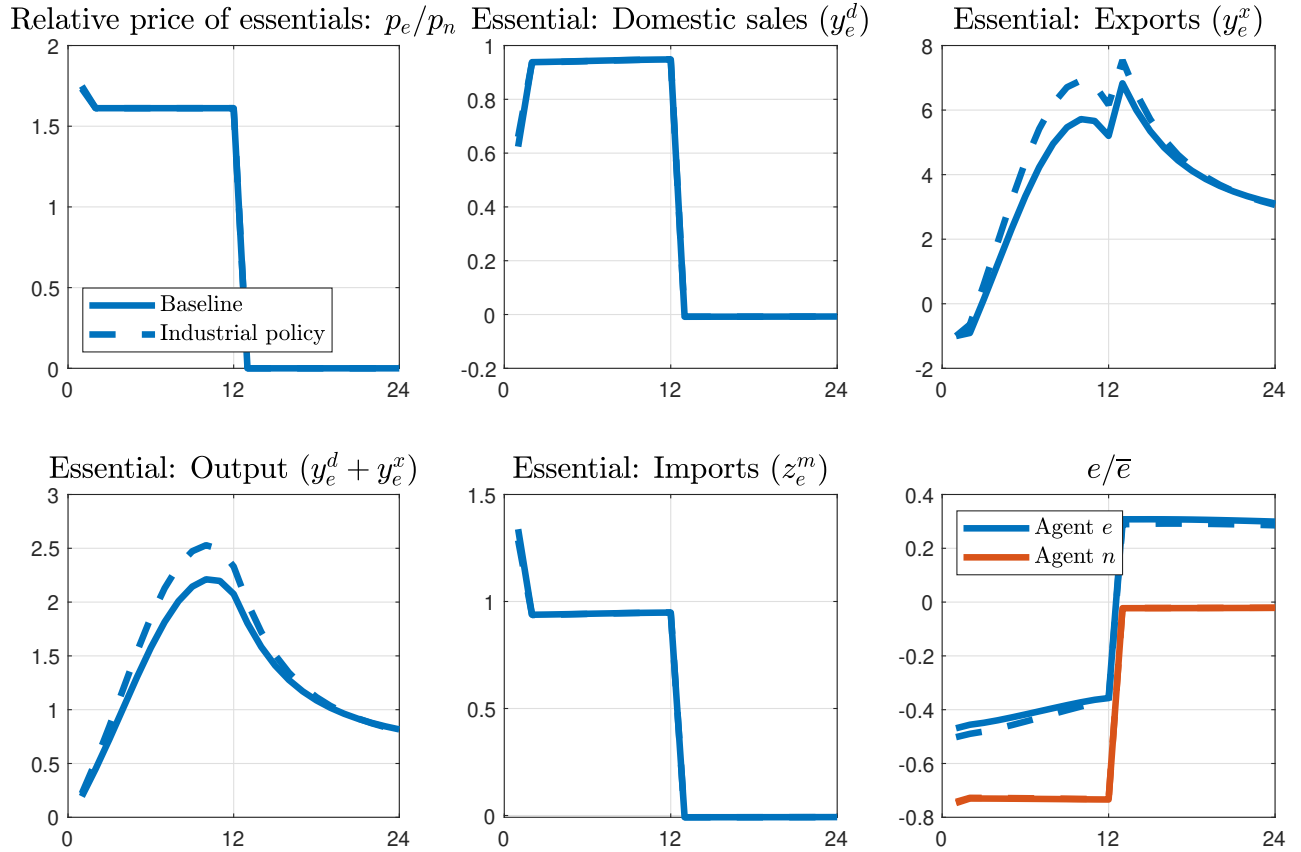


Note: The  $x$ -axes denote time periods (months). The  $y$ -axes are expressed as percent deviations from steady-state. Specifically, percent changes are obtained by multiplying the values in the panel by 100.

**Optimal industrial policy** We now examine the impact of the optimal industrial policy, presented in Figure 6. In contrast to the optimal trade policy, industrial policy leads to an increase in the production of essential goods. This is intuitive, since subsidizing sales of these goods raises the effective return to producing them, leading producers of essential goods to increase their accumulation of physical capital and labor. Yet, we find that industrial policy is not effective at increasing the consumption of essential goods relative to the reference level, despite the increased production. While consumption of these goods declines for households of type  $e$ , it remains virtually unchanged across households of type  $n$ .

The missing link between increased production and consumption is accounted for by international trade: Industrial policy is effective at encouraging firms to increase production of essential goods, but the increased output of these goods is exported rather than sold domestically. Given the price of essential goods is determined internationally, this largely pins

Figure 6: Pandemic dynamics under optimal industrial policy



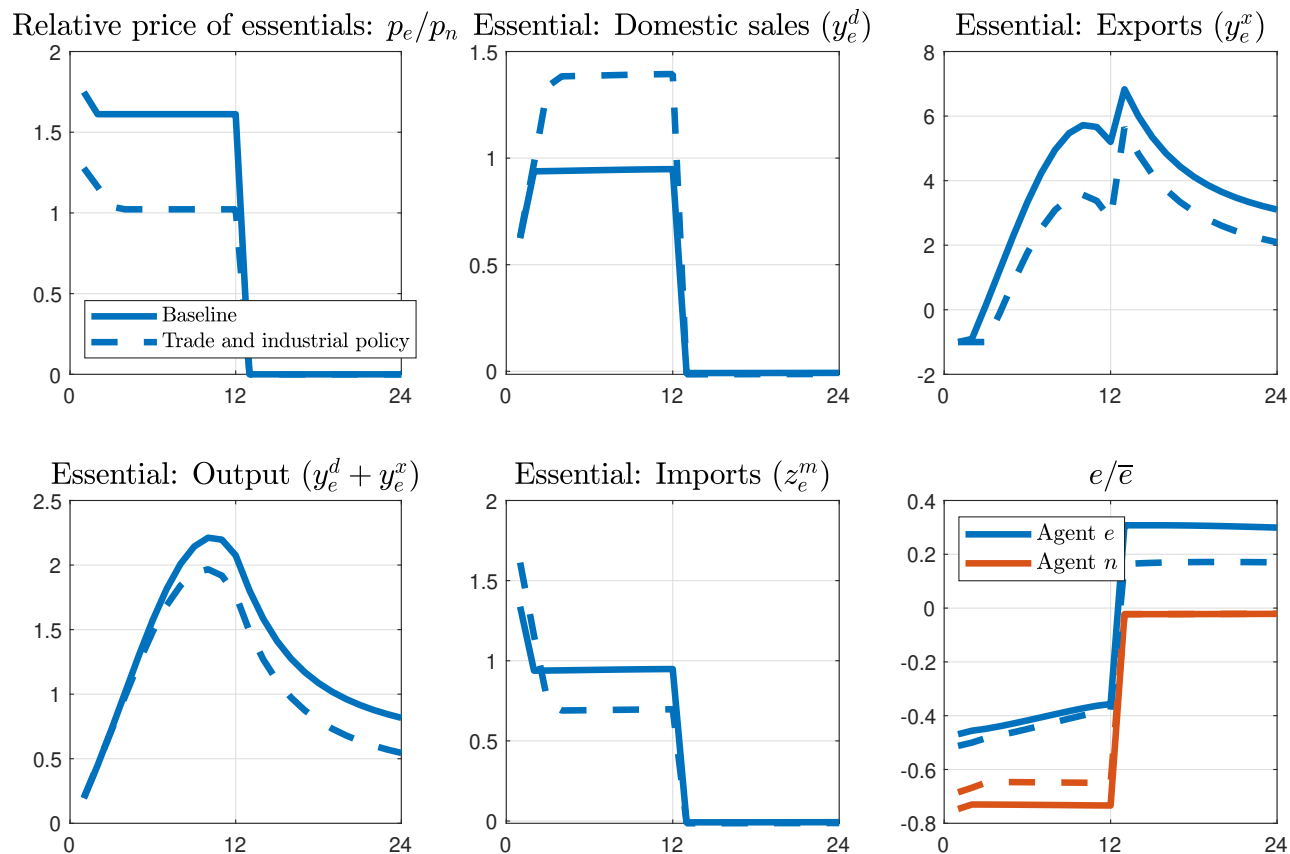
Note: The  $x$ -axes denote time periods (months). The  $y$ -axes are expressed as percent deviations from steady-state. Specifically, percent changes are obtained by multiplying the values in the panel by 100.

down the level of domestic demand, leading most additional output to be sold internationally.

**Optimal trade and industrial policy** The previous findings show that trade and industrial policies have very different impacts on the dynamics following a pandemic. On the one hand, international trade policy is driven by an intra-temporal motive reallocating production across markets at the expense of discouraging investments to increase production. On the other hand, industrial policy is driven by an inter-temporal motive that increases production without consideration for the destination of the additional goods produced. The welfare results presented above show that these policies are complementary in the aftermath of a pandemic — thus, we now investigate their joint impact, presented in Figure 7.

Indeed, we find that trade and industrial policies can jointly increase the consumption of essential goods across most households without discouraging the production of essential goods. While industrial policy provides an incentive to increase production, trade policy

**Figure 7: Pandemic dynamics under optimal trade and industrial policy**



Note: The  $x$ -axes denote time periods (months). The  $y$ -axes are expressed as percent deviations from steady-state. Specifically, percent changes are obtained by multiplying the values in the panel by 100.

realigns firms' incentives to sell the increased production domestically. Given these two types of policies have conflicting impacts on the level of production, their impacts are largely offset by each other, allowing production to remain as in the absence of policy interventions while reallocating sales of essential goods toward domestic households.

#### 5.4 Key channels

We now investigate the key features of our model that account for the role for trade and industrial policy during a pandemic. Tables 6 and 7 report the optimal trade and industrial policies, respectively, under alternative versions of the model. Unless otherwise specified, we compute the results reported in each row of these tables, recalibrating the model to match the pre-pandemic steady-state (Table 3) but keeping the parameters that discipline the pandemic dynamics as in the baseline (Table 4).

**No pandemic** The second row of each table reports the optimal policies in the absence of a pandemic — that is, in the steady-state of the model. We observe that there is no role for either trade or industrial policy in the absence of a pandemic. Thus, the optimal policy interventions are driven by the impact of the shocks and do not arise due to long-run forces that are also active in the steady-state of the model. Particularly critical in accounting for this property of the model are the welfare weights in the government’s objective function and the removal of markup distortions due to monopolistic competition.

**No household heterogeneity** The third row of each table reports the optimal policies in an economy without household heterogeneity. In particular, we consider an economy with one representative household that owns all domestic producers. We find there is no role for either trade or industrial policy in the absence of household heterogeneity.

As described in Section 3, the key distortions in the model arise from the combination of incomplete markets with household heterogeneity, which lead firms to discount the future with the idiosyncratic stochastic discount factor of its owners rather than with a socially-representative rate of discounting. In contrast, in an economy without household heterogeneity, all households and firms discount the future at the same rate despite the absence of complete markets.

**Inter-temporal complementarity** The fourth row of each table reports the optimal policies in an economy with weaker inter-temporal complementarities ( $\xi = 0.50$  instead of  $\xi = 2$ ). We find that the optimal trade and industrial policies are significantly smaller, suggesting a much lower role for policy interventions. A lower value of  $\xi$  implies a higher inter-temporal elasticity of substitution, so households find it easier to reduce consumption during the pandemic in exchange for higher consumption after the pandemic. Thus, the government finds it optimal to avoid the costs involved with adjusting production decisions to increase consumption of essential goods throughout the pandemic.

**Intra-temporal complementarity** The fifth row of each table reports the optimal policies in an economy with weaker intra-temporal complementarities ( $\rho = 0.80$  instead of  $\rho = 0.27$ ). We find that the optimal trade policy is significantly mitigated under weaker intra-temporal complementarities. These allow households to substitute essential with non-essential goods more easily, allowing them to sidestep their increased need and higher prices.

In contrast, we find that the optimal industrial policy is not significantly affected by

**Table 6: Key channels underlying optimal trade policy**

	Export tax	Import tariff
Baseline	14.26%	-9.44%
No pandemic (steady-state)	0.00%	0.00%
No household heterogeneity (representative household)	0.00%	0.00%
Weaker inter-temporal complementarity ( $\xi = 0.50$ vs. $\xi = 2$ )	-0.50%	0.50%
Weaker intra-temporal complementarity ( $\rho = 0.80$ vs. $\rho = 0.27$ )	0.94%	-0.37%
Lower adjustment costs ( $\Omega_{k,e} = \Omega_{\ell,e} = 0$ )	8.83%	-5.62%
Higher adjustment costs ( $\Omega_{k,e} = \Omega_{\ell,e} = 100$ )	19.47%	-29.30%
Financial autarky	18.83%	-11.37%

the degree of intra-temporal complementarities. That is, even if households can more easily substitute essential with non-essential goods, household heterogeneity and incomplete markets imply that firms' investment decisions are not socially optimal. This is intuitive, since industrial policy critically acts by affecting firms' inter-temporal decisions, without much impact on intra-temporal ones.

**Sectoral adjustment costs** The sixth and seventh rows of each table report the optimal policies under alternative sectoral adjustment costs. We find the optimal trade and industrial policies tend to be increasing in the magnitude of the adjustment costs. On the inter-temporal margin, it suggests that firms' production decisions are more sensitive to adjustment costs than socially optimal, leading the government to introduce larger production subsidies than in the baseline. On the intra-temporal margin, it suggests that the higher costs required to increase production imply a higher payoff from introducing policies that rely on reallocating production across markets instead of adjusting the production scale.

**Incomplete markets** Finally, the eighth row of each table reports the optimal policies in an economy under financial autarky. We find the optimal policy response is larger in an environment with more limited access to financial markets. Thus, as discussed in Section 3, incomplete markets play a critical role for our findings.

## 6 Evidence: Trade and industrial policy during shortages of critical goods

The findings reported in the previous section show that trade and industrial policies can be an effective way to unilaterally address shortages of critical goods in an open economy. We

**Table 7: Key channels underlying optimal industrial policy**

	Total sales subsidy
Baseline	12.23%
No pandemic (steady-state)	0.00%
No household heterogeneity (representative household)	0.00%
Weaker inter-temporal complementarity ( $\xi = 0.50$ vs. $\xi = 2$ )	2.33%
Weaker intra-temporal complementarity ( $\rho = 0.80$ vs. $\rho = 0.27$ )	14.43%
Lower adjustment costs ( $\Omega_{k,e} = \Omega_{\ell,e} = 0$ )	16.12%
Higher adjustment costs ( $\Omega_{k,e} = \Omega_{\ell,e} = 100$ )	45.17%
Financial autarky (no bond)	20.96%

now investigate the extent to which these policies are indeed implemented in open economies in response to shortages of critical goods.

### 6.1 Trade and industrial policy interventions during COVID-19

Following the analysis in the previous section, we examine the case of shortages of essential medical goods during COVID-19. To do so, we use data from Global Trade Alert on trade and industrial policy interventions by country and product categories.<sup>29</sup> We restrict our analysis to 16 PPE-related products demanded during COVID-19, as classified by the World Trade Organization (WTO).<sup>30</sup> We use these data to document the evolution in the number of country-product pairs that experienced changes in export restrictions, import liberalizations, and industrial policy interventions between February 2020 and January 2021. To examine the prevalence of policies designed to increase production or curb exports, we restrict attention to country-product pairs with positive exports during 2019.<sup>31</sup>

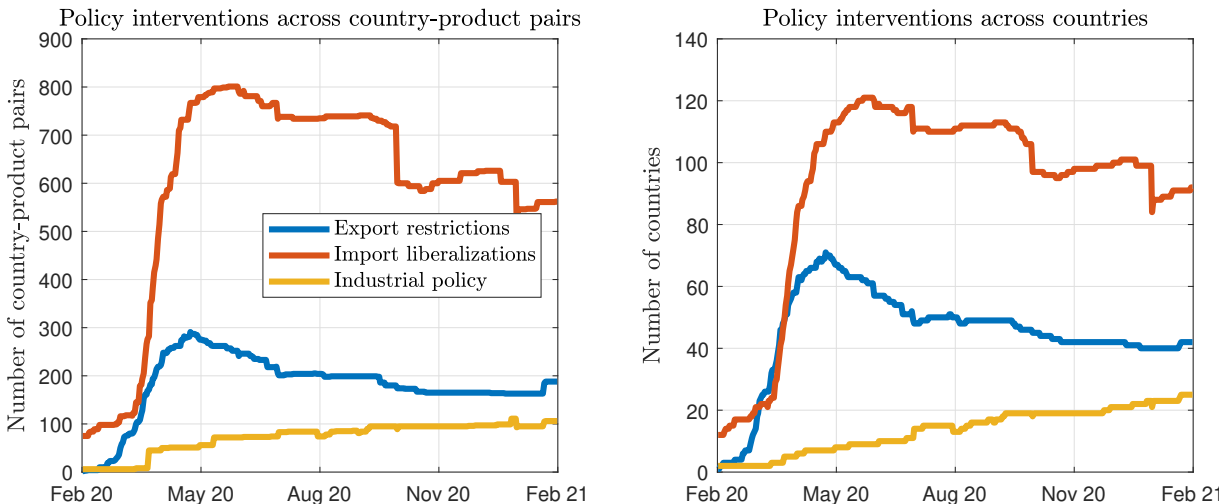
Figure 8 plots the number of country-product pairs and the number of countries over time

<sup>29</sup><https://www.globaltradealert.org/>.

<sup>30</sup>See [https://www.wto.org/english/tratop\\_e/covid19\\_e/covid19\\_e.htm](https://www.wto.org/english/tratop_e/covid19_e/covid19_e.htm) for details on the products that we focus on. The list of 6-digit HS codes is: 340220, 401519, 621010, 630790, 650500, 650610, 842139, 900490, 901812, 901819, 901839, 901920, 902000, 902212, 902214, 902519.

<sup>31</sup>We group the policy interventions reported in the original dataset into the three groups that we study as follows. Export restrictions consist of the tightening or introduction of any of the following policies: export tax, local supply requirement for exports, export licensing requirement, export ban. Import liberalizations consist of the relaxation of any of the following policies: import tariff quota, import tariff, import licensing requirement, internal taxation of imports, import quota, import-related non-tariff measure. Industrial policies consists of the introduction or expansion of any of the following policies: financial grant, state aid, state loan, interest payment subsidy, tax or social insurance relief, loan guarantee, production subsidy, localisation incentive, price stabilization, in-kind grant, capital injection and equity.

**Figure 8: Policy interventions during COVID-19**



Note: The x-axis corresponds to months. We restrict attention to trade policy changes on essential medical goods as classified in the text. We focus on country-product pairs with positive exports.

with policies to restrict exports, liberalize imports, and encourage production. The figure shows a big spike in the number of trade and industrial policy interventions from February 2020 to January 2021. We interpret this increase in the number of policies introduced throughout COVID-19 to curb exports, ease imports, and promote production of essential medical goods as consistent with the implications of the model.

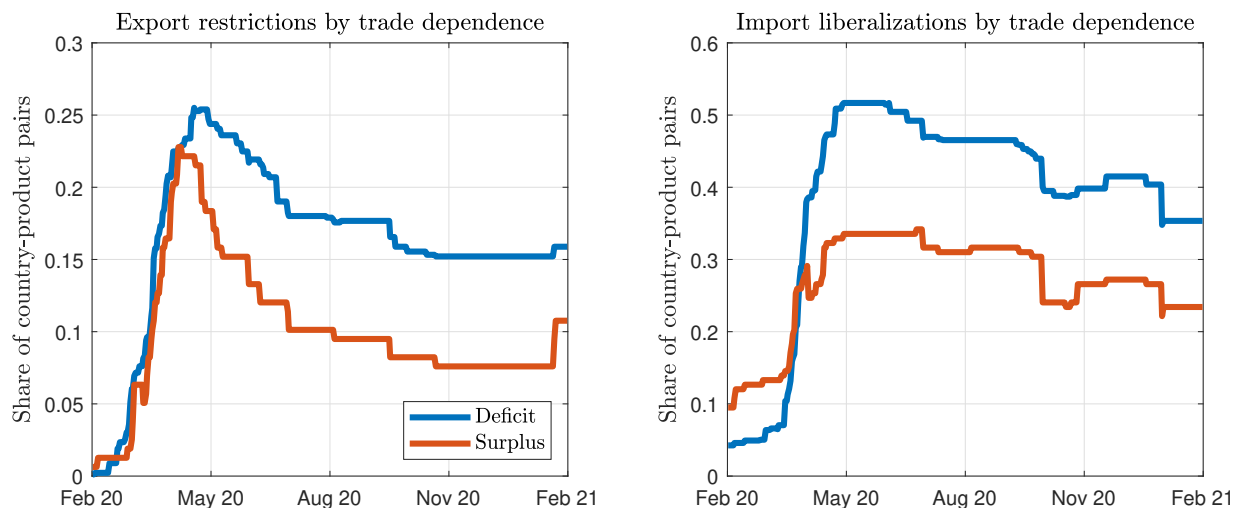
For instance, by the end of April 2020, 279 country-product pairs were subject to newly introduced export restrictions, 779 had experienced a liberalization of import restrictions, and 51 were subject to industrial policies. While trade policy interventions were mostly temporary, many were still in place a year into the pandemic. For instance, by the end of January 2021, there were still 188 and 562 export restrictions and import liberalizations in place, respectively. In contrast, production subsidies were introduced gradually and still increasing, going from 51 in April 2020 to 106 in January 2021. Similar patterns are observed across countries.

## 6.2 Trade dependence and policy interventions during COVID-19

The previous findings show that, consistent with the implications of the model, trade and industrial policies were a prevalent response to shortages of essential medical goods experienced during COVID-19. We now examine whether the likelihood of these responses depended on countries' dependence on international trade to access such products.



**Figure 9: Policy interventions during COVID-19 by trade dependence**



Note: The x-axis corresponds to months. We restrict attention to trade policy changes on essential medical goods as classified in the text. We focus on country-product pairs with positive exports.

We start by measuring a country’s trade dependence to access a given product based on its trade imbalance. We classify country-product pairs into groups based on their trade imbalance in 2019 using data from CEPII: country-pairs with a trade deficit and those with a surplus.<sup>32</sup> For each of these groups, Figure 9 plots the evolution of the share of country-product pairs with export restrictions and import liberalizations.

We find that country-product pairs with trade deficits prior to the pandemic were more likely to be subject to trade policy interventions. On the one hand, the share of country-product pairs subject to import liberalizations is larger among those with deficits prior to the pandemic. In contrast, when it came to export restrictions, the number and pace of interventions during the first months of the pandemic were relatively similar regardless of whether such products had surpluses or deficits. Export restrictions, however, were removed faster among country-product pairs with a trade surplus, suggesting that countries with a comparative advantage in these products were better equipped to scale up production in the face of global shortages.

We conclude by contrasting these empirical findings with the implications of the model. We examine whether the optimal trade policy interventions also depend on the degree of international trade dependence. To do so, we investigate two counter-factual economies

<sup>32</sup>[http://www.cepii.fr/CEPII/en/bdd\\_modele/bdd\\_modele.asp](http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele.asp).

**Table 8: Optimal trade policy and sectoral imbalances**

	Export tax	Import tariff
Trade deficit of essential goods ( $NX_e/GDP_e = -0.30$ )	15.40%	- 9.81%
Trade surplus of essential goods ( $NX_e/GDP_e = 0.30$ )	8.29%	- 5.30%

with alternative degrees of international trade dependence on essential goods. In particular, we keep the parameters from Table 4 as in the baseline, and we recalibrate the parameters from Table 3 targeting a net exports-to-GDP ratio in essential goods equal to  $\pm 0.30$ .

We report our findings in Table 8. As in the data, we find both sets of countries find it optimal to introduce policies that restrict exports and liberalize imports. Moreover, we find that countries with a trade deficit of essential goods introduce larger trade policy interventions: Export taxes and import subsidies are both higher in these countries than among those with a surplus. We interpret this difference in optimal trade policy interventions as consistent with the evidence documented above: Economies with greater deficits in essential goods respond more strongly to shortages of these goods.

## 7 Concluding remarks

This paper studies the role for international trade and industrial policy interventions in response to shortages of essential goods. We find that the unilateral optimal trade policy response is to tax exports while subsidizing imports and domestic production. On the one hand, import subsidies allow countries to increase their consumption of essential goods, while export taxes lead domestic producers to reallocate sales from exports toward domestic consumers. On the other hand, industrial policy allows countries to scale up production of essential goods. These findings are consistent with evidence on changes in trade barriers and industrial policy observed across countries during COVID-19.

Our analysis reveals that ownership heterogeneity and incomplete markets can be critical in generating underinvestment and underhiring following a shock that increases demand for critical goods. Moreover, we find that inter-temporal complementarities, intra-temporal complementarities, and production adjustment costs are also important for the quantitative importance of our findings.

But our findings also naturally depend on other important features of the analysis. For instance, our focus on a global shock is also significant. Absent these price increases, increasing consumption of essential goods would be much easier and less costly. Similarly,

our analysis restricts attention to the optimal unilateral design of international trade policy. Thus, these findings raise key questions about the potential to identify multilateral trade policy solutions that dominate the incentives to adjust trade policy unilaterally. While a broader multilateral analysis of optimal trade policy is beyond the scope of the paper, this is an important area to be examined in future research.

Finally, we restrict attention to the design of policy interventions from an ex-post perspective; that is, we focus on the optimal response after the onset of shortages. The analysis of policy design ex-post limits the set of instruments that one could examine since policies such as ensuring sufficient stockpiles of essential goods could only be beneficial if implemented prior to the onset of shortages. Further analysis of policies ex-ante is likely to be a fruitful area for future research.

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