

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

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Abstract

This paper studies the role for optimal trade and industrial policy to mitigate shortages of critical goods following global shocks. We develop a dynamic model of trade with producers of essential and non-essential goods owned by heterogeneous households under incomplete markets. Shocks that increase global demand for critical goods lead to 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 following recent shocks.

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1 Introduction

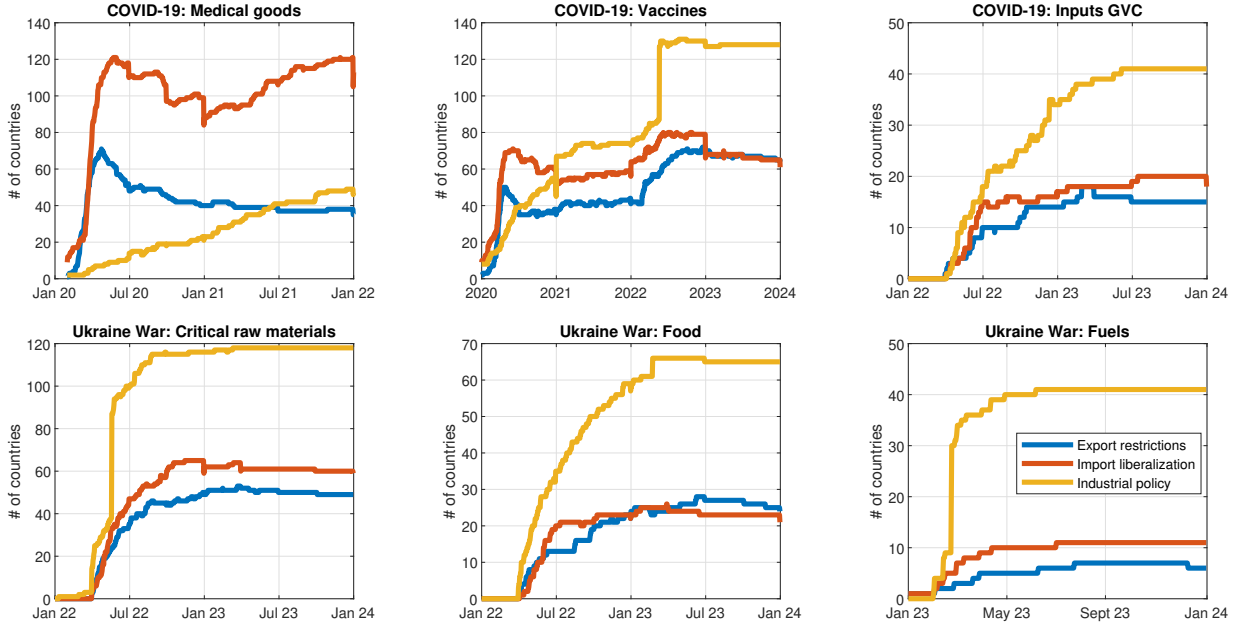
After decades of trade liberalization, the world is experiencing a return to protectionism. Recent events like the Russian invasion of Ukraine, growing geopolitical tension between the U.S. and China, and the COVID-19 pandemic have exposed the vulnerability of modern economies to heavy dependence on imports of critical goods such as semiconductors, energy and commodities, and personal protective equipment (PPE). Shortages of these goods during these episodes have raised questions about the potential role for policy interventions to mitigate them. Our paper studies optimal trade and industrial policy in the aftermath of global shocks through the lens of a quantitative dynamic multi-sector trade model.

Indeed, in the aftermath of Russia’s invasion of Ukraine and the COVID-19 pandemic, there was a sharp increase in the number of countries that introduced policies to mitigate shortages of goods affected by these episodes: raw materials, food, and fuels during the Ukraine war; medical goods, vaccines, and global value chain inputs — e.g., semiconductors — during COVID-19. Figure 1, based on data from Global Trade Alert, suggests countries attempted to address shortages of these goods by restricting exports, liberalizing imports, and promoting domestic production.

Motivated by this evidence, we ask: To what extent is it optimal to introduce trade and industrial policies to mitigate shortages of critical goods in the aftermath of global shocks? To address this question, we study a quantitative general equilibrium model of international trade. We use the model to investigate the optimality of using trade and industrial policies to address global shortages of critical goods, and we contrast the implications of the model with evidence from the data. Our main contribution to the literature is to study and quantify a novel motive for trade and industrial policy interventions arising from the dynamic adjustment to global shocks.

Despite significant specialization of production across countries, domestic firms can often adjust production ex-post to mitigate the impact of such shortages. However, firms may not sufficiently adjust production if social returns and private costs are misaligned. In particular, if adjusting production requires firms to undertake large investments financed with its owners’ internal resources, then production may increase less than socially optimal. Thus, in this paper we study the role of the following channels in mediating firms’ intertemporal investment trade-off: *(i)* frictions in financial markets, and *(ii)* the imperfect diversification of firm ownership across households. In an environment with these features, producers may

Figure 1: Trade and industrial policies following global shocks



Note: The data is from Global Trade Alert's "The Essential Goods Initiative+: Tracking policies in essential goods including Food, Fuel, Critical Raw Materials and Medical Products."

underinvest relative to the first-best, introducing a role for policy.

The first channel is motivated by numerous studies documenting the pervasiveness of financial market frictions in both emerging and developed economies (Buera, Kaboski, and Shin 2011; Midrigan and Xu 2014; Dinlersoz et al. 2018; Leibovici and Wiczer 2023). The second channel is motivated by evidence on the concentration of firm ownership that we summarize in Table 1. In both the U.S. and Europe, ownership of private firms is highly concentrated, with the vast majority primarily owned and controlled by a single individual. While ownership of public firms is much less concentrated in both the U.S. and Europe, it is nevertheless significantly concentrated — the top 20 owners account for more than 56% of the firms' value on average. Thus, firm ownership is significantly concentrated and far from perfectly diversified across individuals.¹ The combination of these two channels implies that, in the face of an investment opportunity, firms may underinvest relative to an economy without financial market frictions or with perfectly diversified firm ownership.

To study the role of trade and industrial policies to mitigate shortages of critical goods,

¹See also 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.

Table 1: Ownership Concentration in the U.S. and Europe

| Firm type | Statistic | Value | Source |
|----------------------|--|-------|--------------|
| <i>United States</i> | | | |
| Private | Share of firms with < 4 owners | 97.4% | SBO |
| Private | Out of these: Avg. ownership share of top owner | 86.2% | SBO |
| Public | Avg. ownership share of top 3 owners | 23% | OECD |
| Public | Avg. ownership share of top 20 owners | 56% | OECD |
| <i>Europe</i> | | | |
| Private | Share of firms owned by single household | 74% | Peter (2021) |
| Private | Share of firms with single household owns $> 50\%$ | 90% | Peter (2021) |
| Public | Avg. ownership share of top 3 owners | 49% | OECD |
| Public | Avg. ownership share of top 20 owners | 66% | OECD |

Note: The data on private firms in the U.S. is based on authors' calculations from the U.S. Census Bureau's 2007 Survey of Business Owners (SBO). The data on private firms in Europe is from Peter (2021). The data on public firms is from De La Cruz, Medina, and Tang (2019) — an OECD report with ownership information on public firms across countries. The values corresponding to this report are approximated based on the report's figures.

we set up 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. Our specification captures key dimensions along which essential goods may differ from non-essential goods. First, essential and non-essential goods are complementary with each other. Thus, even if essential goods constitute a small fraction of aggregate absorption, shocks to the demand or supply of these goods may have significant aggregate implications if complementarities are sufficiently strong. Second, the contribution of essential goods to the production of final goods is relative to a time-varying reference level, capturing changes in the level of need for these goods — e.g., an increase in the need for PPE 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. 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 ownership shares of either essential or non-essential goods producers. Motivated by the evidence in Table 1 on firm ownership concentration,

we assume firm ownership is not perfectly diversified across households. Thus, essential and non-essential goods producers make forward-looking decisions by discounting profits with their owners' stochastic discount factor.

We model shortages of essential goods as arising from a global increase in their demand — the analysis, however, is analogous for shortages that arise from decreased supply. Domestically, higher demand is captured by an increase in the reference level of essential goods. Internationally, higher demand is captured by an increase in the price of imports and exports of essential goods. The higher domestic and export prices lead producers to increase the production scale. But as owners borrow to finance capital accumulation and labor hiring, incomplete financial markets lead them to trade off current consumption for higher future consumption, reducing their discount rate and lowering the returns to increasing production.

We begin by qualitatively characterizing equilibrium outcomes relative to the first best. First, we show that incomplete financial markets and ownership heterogeneity imply that household stochastic discount rates are heterogeneous across households in the competitive equilibrium. Second, we show that the solution to the social planner's problem implies that stochastic discount factors are equalized across households. Thus, we conclude that the competitive equilibrium is inefficient. The difference between the equilibrium and the first best is captured by a time-varying wedge in the firms' first order conditions for capital and labor. In the face of a global demand shock, firms' incentives to scale up production are lower than in the first best. These findings show the potential for policy interventions to increase welfare.

We use our model to quantify the aggregate implications 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. prior to and during the COVID-19 pandemic. 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. We model the global increase in the demand for these goods as an increase in the reference level of essential goods, along with an increase in export and import prices, capturing the higher global need for these goods. We assume the shocks are transitory and unexpected, and that the agents operate under perfect foresight.

Our estimates imply that essential and non-essential goods are complementary and that

capital investment and labor hiring are subject to significant adjustment costs. These estimates 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.

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 on the trade and production of essential goods: 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 shocks to maximize a population-weighted utilitarian social welfare function. As in Itskhoki and Moll (2019), we restrict attention to investigating the desirability of realistic policy instruments that have been widely implemented across countries. We additionally do not allow for direct transfers of resources across households, and we remove markup distortions to ensure there is no role for policy interventions in the steady-state.

When we only allow for trade 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 contrast, when we only allow for industrial 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, the gains from 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. Trade

and industrial policies jointly increase the consumption of essential goods across 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. The complementarity between trade and industrial policy is consistent with the simultaneous implementation of these policies across countries, as observed in Figure 1. In particular, our findings are consistent with policy interventions in the U.S. in the aftermath of COVID-19 — for instance, the Defense Production Act was used to increase production of PPE and vaccines, while limiting sales abroad (Bown 2022).

While we abstract from policies that directly redistribute resources, our policy instruments increase welfare by indirectly affecting agents’ resources in two ways. Either by increasing the aggregate amount of goods consumed domestically (efficiency), or by changing the relative level of consumption across agents (redistribution). We decompose the relative importance of these motives in accounting for our optimal policy findings following Benabou (2002) and Boar and Midrigan (2022). We conclude efficiency considerations account for 2/3 of the policy interventions we find, while redistributive considerations account for the rest.

We then investigate the key channels underlying our findings. We show that intra- and inter-temporal complementarities, as well as sectoral adjustment costs, are quantitatively important in accounting for our findings. Policies that promote production and consumption of essential goods have a lower payoff if households (firms) find it easier to reallocate consumption (production) across time or sectors.

We conclude by contrasting our findings with evidence on trade and industrial policy interventions across countries during COVID-19. To do so, we use data from Global Trade Alert on policies introduced to affect trade and production of goods critical to combat the disease. 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.

Related Literature Our paper contributes to large literatures that study optimal trade policy in open economies with heterogeneous firms (Costinot, Rodríguez-Clare, and Werning 2020; Demidova and Rodríguez-Clare 2009), and optimal industrial policy as means to

achieve long-term development (Juhász, Lane, and Rodrik 2023; Caliendo and Parro 2022; Bartelme et al. 2019; Lashkaripour and Lugovskyy 2023). In contrast to much of the literature, our paper studies the role for optimal trade and industrial 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.

The role for policy interventions in our economy arises from the combination of incomplete markets and the concentration of firm ownership across a subset of the population. This channel is most closely related to Itskhoki and Moll (2019) and Caballero and Lorenzoni (2014), who study optimal policy design in dynamic environments where firms’ decisions are distorted by frictions in financial markets.

Our paper is also related to recent studies on the aggregate importance of small but systemic sectors. Baqaee and Farhi (2019b) and Baqaee and Farhi (2019a) show 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. We study the policy implications of related forces using a dynamic environment with goods 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 (2023) and Grossman, Helpman, and Lhuillier (2021) study the role for policy interventions ex-ante rather than ex-post, as we do in our work. 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 shocks across countries (Cakmakli et al. 2021; Bonadio et al. 2021; LaBelle, Leibovici, and Santacreu 2021; Antràs, Redding, and Rossi-Hansberg 2023; Eppinger et al. 2021).

2 Model

We study a small open economy that trades goods and financial assets with the rest of the world. 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. Sectoral varieties 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. All varieties can be traded internationally — thus, the 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 non-essential varieties be the numeraire. Varieties in each sector are produced using labor and capital, which are mobile across sectors. Sectoral composite goods aggregate domestic and imported varieties in each sector, and final goods aggregate sectoral composite goods across sectors. In the rest of this section, we describe each of these agents in detail.

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 λ_i units of labor and own producers of the domestic variety of good i .² Labor is supplied inelastically to an economy-wide labor market at wage rate w_t .³ Thus, every period households earn labor income $\lambda_i w_t$ as well as the profits or losses π_{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.⁴

As in Bewley-Huggett-Aiyagari models (Bewley, 1977; Huggett, 1993; Aiyagari, 1994), we assume that households have access to incomplete financial markets. 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 goods, where Ω_b is a constant that controls the cost of bond-holding deviations from 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:

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

²We normalize the economy's aggregate labor supply to unity — thus, $\lambda_n + \lambda_e = 1$.

³Labor is freely mobile across sectors, so the wage is equalized.

⁴ $\mathcal{T}_{it} < 0$ denotes a lump-sum tax.

where c_{it} is consumption of final goods, p_t is the price of final goods, p_{nt} is the price of the non-essential good composite, and $b_{it+1} > 0$ ($b_{it+1} < 0$) denotes debt (savings).

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 is:

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

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 Producers of final goods

The final goods purchased by households and firms are produced by a representative firm 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 γ controls the relative importance of the two goods for the aggregate absorption bundle, ρ 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 they are complementary with non-essential goods ($\rho < 1$) — in Section 4 we estimate this to be the case.

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

$$\max_{y_t, n_t, e_t} p_t y_t - p_{nt} n_t - p_{et} e_t$$

subject to

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

The goal of this specification is to capture key dimensions along which essential goods may differ from non-essential goods. First, essential and non-essential goods are complementary

with each other. Thus, even if essential goods constitute a small fraction of aggregate absorption, shocks to the demand or supply of these goods may have significant aggregate implications if complementarities are sufficiently strong. Second, 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 . This captures that demand for some goods is often evaluated relative to the perceived need for them. Finally, this specification allows us to capture the importance of essential goods for either consumption or production. In particular, 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.

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

The sectoral composite goods used to produce final goods are themselves produced by combining sectoral varieties 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 , respectively. Imports are subject to iceberg trade costs τ_j and import tariffs τ_{jt}^m that are ad-valorem and such that $\tau_j \geq 1$.⁵

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

$$\max_{y_{jt}, q_{jt}^d, q_{jt}^m} p_{jt} y_{jt} - p_{jt}^d q_{jt}^d - (1 + \tau_{jt}^m) \tau_j p_{jt}^m q_{jt}^m$$

subject to

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

⁵Negative import tariffs denote import subsidies.

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

Domestic varieties in sector $j \in \{n, e\}$ are produced by a representative firm using capital k_{jt} and labor ℓ_{jt} , with a time-invariant productivity A_j . The amount produced in each sector j is given by $A_j \left(\ell_{jt}^\alpha k_{jt}^{1-\alpha} \right)^\eta$, where α controls the labor share, $1 - \alpha$ controls the capital share, and $\eta \in (0, 1)$ denotes the degree of decreasing returns to scale.⁶

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. Thus, 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 δ , 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 change over time. We assume that capital and labor adjustment costs are quadratic and denominated in units of non-essential goods:

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

where Ω_{kj} 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 τ_{jt}^x , and total sales are subject to an ad-valorem subsidy τ_{jt}^y .⁷

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} . Given that the representative firm that produces domestic variety j is owned by households of type j , the firm values returns across time periods and states of the world according to its owners' stochastic discount factor m_{jt} .⁸ The firm's problem is then given

⁶We 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.

⁷Negative export taxes denote export subsidies, and negative sales subsidies denote taxes.

⁸The stochastic discount factor of households of type i is given by $m_{it+1} = \beta \frac{\partial u_i(n_{it+1}, e_{it+1}) / \partial e_{it+1}}{\partial u_i(n_{it}, e_{it}) / \partial e_{it}}$.

by:

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

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. The third constraint consists of the demand function faced domestically, which results from the problem of producers of composite good j described above.⁹ Given the perfectly elastic demand faced from the rest of the world, the fourth constraint ensures exports are weakly positive.

2.5 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 τ_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 .

2.6 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 $\{\tau_{jt}^x\}_{j \in \{n, e\}}$, and which uses these revenues to subsidize

⁹We 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.

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:

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

Given a set of taxes and subsidies, there are multiple configurations of lump-sum transfers that can ensure the budget is balanced. To characterize the multiple arrangements available, we let $\psi_{ijt}^k \in (0, 1)$ 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:

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

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 the 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 problem of each household type
2. Given prices, allocations solve problem of final good producers

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

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

11. 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. Given that we study a small open economy, we consider an analogous increase in the need for essential goods in the rest of the world through an unexpected increase in the price of imports and exports of essential goods, p_{et}^m and p_{et}^x .

3.1 Demand response

We first study the impact of these shocks on the demand for essential goods. The increase of \bar{e}_t means expenditures on essential goods need to be increased to achieve the reference level. Final goods producers are further discouraged to purchase these goods due to the increase in their prices: domestic and imported varieties of essential goods become more expensive due to higher export and import prices. In particular, given that producers of domestic varieties sell both domestically and abroad, the higher price of exports leads firms to increase domestic prices. Yet, demand for essential goods increases: While substituting

essential with non-essential goods would mitigate their exposure to the shocks, intra-temporal complementarities imply final good 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 essential with non-essential goods. Instead, the increase in the reference level leads to an increase in the demand for essential goods as can be observed from:

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

which shows that the higher value of \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 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, households have preferences represented through a constant relative risk aversion utility function, which features a finite intertemporal elasticity of substitution $1/\xi < \infty$. Then, households find it costly to substitute consumption 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 does not fully offset the changes in prices.

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. One way to increase the supply of essential goods is via international trade: increasing imports and/or reallocating exports toward domestic sales. However, while feasible, these adjustments are costly given the higher global prices. An alternative, then, is to increase production. To study how firms adjust production after a large demand shock, it is instructive to examine

producers' first-order conditions for labor and capital¹⁰:

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

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+1} .

In our model, markets clear and demand and supply of essential goods is equalized in equilibrium. However, the large increase of \bar{e} may not result in a sufficiently large supply response to increase purchases of essential goods up to their higher need. As a result, there are shortages of essential goods following the shock — $e < \bar{e}$.

Given that households operate under incomplete financial markets, bond-holding 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 household's Euler equation is given by:

$$\mathbb{E}_t m_{it+1} = \frac{1}{1+r} - p_{nt} \Omega_b (b_{it+1} - \bar{b}). \quad (1)$$

Thus, as the households that own producers of essential goods borrow to finance the production increase and to increase consumption due to the rise of permanent income, the

¹⁰To ease the exposition, we abstract here from export taxes and sales subsidies, setting them to zero.

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.

The following proposition summarizes the conditions under which the household's stochastic discount factor is heterogeneous across households:

Proposition 1. *If households are heterogeneous and financial markets are incomplete ($\Omega_b > 0$), then the competitive equilibrium features households with heterogeneous stochastic discount factors: $m_{et+1} \neq m_{nt+1}$.*

3.3 Efficiency

Given these demand and supply responses, we then ask: To what extent is the equilibrium availability of essential goods distorted relative to the first-best? To answer this question, we contrast the equilibrium response of our economy vis-a-vis the response of an economy where decisions are made by a social planner that is subject to the same technological constraints as the agents in our economy. To simplify the analysis, we restrict attention to an economy with high bond-holding costs — specifically, we consider $\Omega_b \rightarrow \infty$.

We begin by examining how the rate at which agents substitute consumption across time and states of the world varies across agents. We find that:

Proposition 2. *The solution to the social planner's problem consists of equalizing the stochastic discount factors across agents: $m_{nt+1} = m_{et+1} \quad \forall t$. We denote this common discount rate as \widetilde{m}_{t+1} .*

While the planner and equilibrium of the domestic economy are based on an environment under imperfect international financial integration, the planner is able to complete domestic financial markets allowing households to share risk between them. Thus, the solution of the planner's problem ensures that the households discount future states of the world at an identical rate.

A direct corollary of Propositions 1 and 2 is that the competitive equilibrium is inefficient:

Corollary 1. *If households are heterogeneous and financial markets are incomplete, then the competitive equilibrium is inefficient.*

We then examine how the planner makes production decisions:

Proposition 3. *The planner's choice of labor and capital are characterized by their respective first-order conditions:*

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

$$\mathbb{E}_t \left\{ \tilde{m}_{t+1} \left[q_{et+1}^x \eta (1-\alpha) \ell_{et+1}^{\alpha \eta} k_{et+1}^{\eta(1-\alpha)-1} + (1-\delta) \tilde{p}_{nt+1} + \tilde{p}_{nt+1} \frac{\partial \phi_{ket+1}}{\partial k_{et+2}} \right] \right\} = \tilde{p}_{nt} \left[1 + \frac{\partial \phi_{ket}}{\partial k_{et+1}} \right],$$

where \tilde{p}_{nt} is the same function of allocations as its competitive equilibrium counterpart. These first-order conditions are identical to those made by firms in the competitive equilibrium, with one exception: instead of discounting future payoffs with a household-specific stochastic discount factor, the planner uses a discount rate that is common across households.

Proposition 3 shows that production decisions differ between the competitive equilibrium and the first best. An open question, then, is: To what extent is there indeed underproduction in the competitive equilibrium relative to the first best? We argue that, indeed, firms in the competitive equilibrium under-invest relative to the first best. While discounting of future payoffs increases in both as investments increase, firms discount future payoffs relatively more in the competitive equilibrium as investments are financed with the resources of the particular owner, not with the economy-wide resources.

That is, shortages are exacerbated by the presence of incomplete markets and household heterogeneity. These lead 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

While our model can be used to study shortages of critical goods in different episodes, we focus on particular application: shortages of essential medical goods during the outbreak of COVID-19. We use this episode to explore the quantitative importance of the channels outlined in the previous section and evaluate the role of policy interventions. 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 this episode 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.

To examine the dynamics of demand and supply of personal protective equipment (PPE) during COVID-19 in the U.S., we use data from the White House COVID-19 Supply Chain Task Force.¹¹ As in these data, we focus on the following types of PPE: N95 respirators, surgical masks, gloves, and face shields. We interpret the evidence we document on these goods as representative of the broader set of PPE required to prevent the spread of COVID-19.

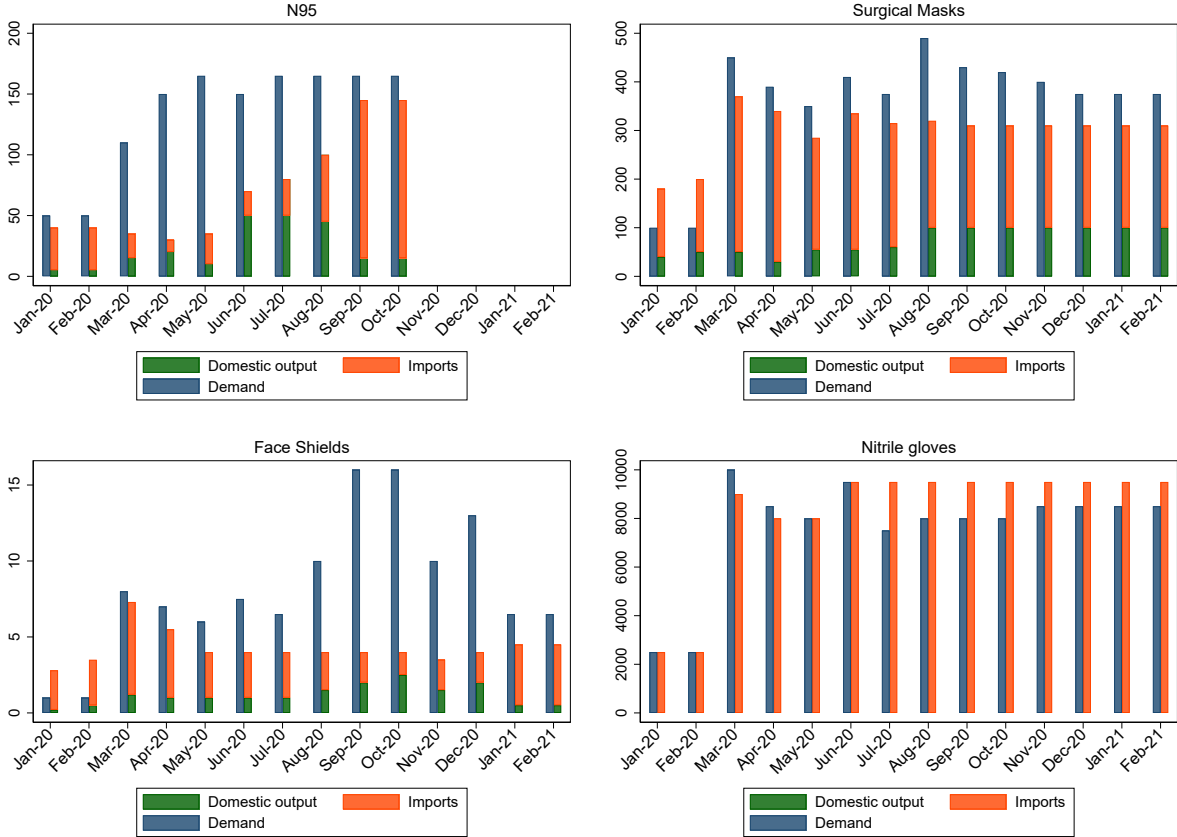
Demand vs. supply of personal protective equipment We begin by documenting the evolution of demand and supply of PPE that has been critical to prevent the transmission of COVID-19. Our analysis is based on estimates of the demand and supply of these goods reported by the task force for Jan 2020 - Feb 2021, right before the introduction of COVID-19 vaccines. Figure 2 reports our findings, with blue bars representing PPE demand as 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.

¹¹See <https://crsreports.congress.gov/product/pdf/R/R46628>.

Figure 2: PPE Demand and Supply in the U.S., Jan 2020 – Feb 2021



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

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 shortages of essential goods for 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. We obtain information on price changes by combining 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 cate-

Table 2: 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.

gories. 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, we compute the peak price change in 2020 relative to its 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 2020.¹² Thus, we obtain prices of N95 masks from a study conducted by The Society for Healthcare Organization Procurement Professionals (SHOPP) in April 2020.¹³ 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 2. We find that the price of PPE increased substantially during the pandemic, likely reflecting the severe supply shortages documented above. Relative 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).¹⁴

¹²The July 1st, 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.

¹³See <https://shopp.org/>.

¹⁴See Cabral and Xu (2021) for a detailed analysis of the role of price gouging on observed price changes.

4.2 Global demand shock in the model

Motivated by this evidence, we model a pandemic in our model as consisting of a global increase in the demand for essential goods. Given the small open economy nature of the model, we implement it 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 .¹⁵

Note that our approach is to focus on the policy implications of sudden and large changes in the demand for critical goods rather than to explicitly model a pandemic. Thus, we abstract from other salient features of the pandemic, like explicitly modeling the spread of the disease and its impact on the economy (e.g., Çakmaklı et al. 2023).

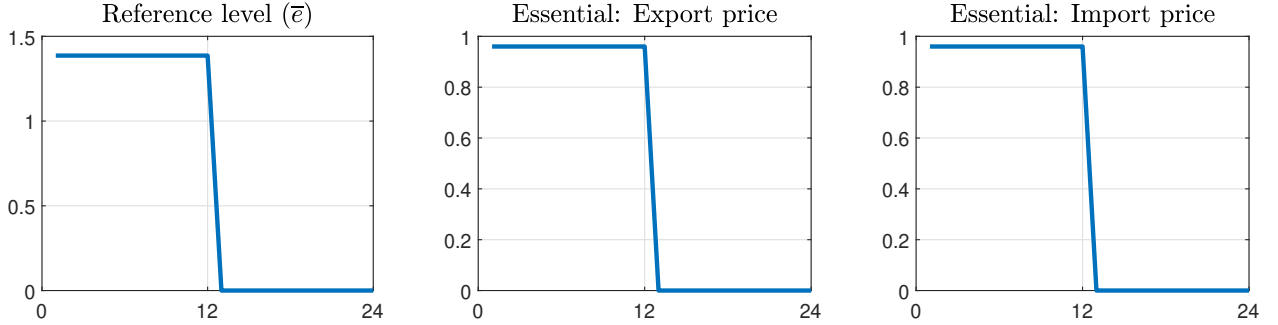
Given the high frequency dynamics of the pandemic, we interpret a period in the model as a month in the data. And given our focus on shortages of essential medical goods prior to the development of vaccines, we study shocks that last for 12 months. We study the perfect foresight solution of the model in response to these shocks. We let period 0 denote the initial steady state. The full path of shocks is observed in period 1. Agents observe an increase of \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. To simplify the analysis, we assume that each shocked parameter increases once before reverting back to steady state.

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. We set the shock to the reference level \bar{e} to match the increased demand for these goods documented in Figure 2. 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 3 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

¹⁵To simplify the analysis, we assume that import and export prices increase by the same amount.

Figure 3: Global demand shock



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

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.¹⁶ For each good we identify the highest price change relative to pre-pandemic prices, and then compute the median across goods. While we rely on the same data used for Table 2, here we pool all underlying product codes and abstract from the broad product categories. 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 parameterize 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 U.S. economy following COVID-19.

Predetermined parameters Predetermined parameters are set to standard values from the literature and consist of the discount factor β , the intertemporal elasticity of substitution $1/\xi$, the elasticity of substitution between domestic and imported varieties of essential and non-essential goods σ , the labor share α , the degree of returns to scale η , and the capital depreciation rate δ . We normalize weights ω_e and ω_c to $1/2$, and the productivity of essential goods producers to 1.

¹⁶We restrict attention to products with non-missing data throughout the first 12 months of the pandemic. Thus, we exclude N95 masks since they were not separately reported prior to July 2020.

Table 3: Predetermined parameters

| Parameter | Value | Description |
|-----------------------|-----------------------|--|
| β | $0.96^{\frac{1}{12}}$ | Discount factor |
| $1/\xi$ | 0.50 | Intertemporal elasticity of substitution |
| σ | 4 | Armington elasticity |
| α | 0.66 | Labor share |
| η | 0.85 | Returns to scale |
| δ | 0.01 | Capital depreciation rate |
| $\omega_e = \omega_c$ | 0.50 | Weight on home goods |
| A_e | 1 | Productivity of essential goods sector |

Table 3 reports the parameter values used throughout. We set β 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 σ is set to 4 following Simonovska and Waugh (2014), implying that domestic and imported varieties are relatively substitutable. We set the labor share α to $2/3$ and returns to scale η to 0.85 following Midrigan and Xu (2014) and Atkeson and Kehoe (2007). We set the monthly depreciation rate δ 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 shocks 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 τ_e and τ_n , the reference level of essential goods \bar{e} in the steady state, the weight γ of essential goods in the technology of final goods producers, the measures λ_n and λ_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.

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, $\bar{b}_e = \frac{\lambda_e}{1 - \lambda_e} \bar{b}_n$.

Table 4: Estimated parameters, pre-shock steady state

| Parameter | Value | Description |
|-----------------------|-------------------------------------|---------------------------------------|
| A_n | 1.591 | Sectoral productivity |
| τ_e | 0.138 | Trade costs on essential goods |
| τ_n | 0.342 | Trade costs on non-essential goods |
| \bar{e} | 0.326 | Reference level of essential goods |
| γ | 0.001 | Utility weight on essential goods |
| λ_n | 0.957 | Measure of agents of type n |
| \bar{b}_n | -147.89 | Steady-state level of debt: Agent n |
| λ_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 |

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-19.¹⁷ Thus, we define

¹⁷The key constraint that we face is that the product-level gross output data are not sufficiently disaggre-

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.¹⁸ We compute all moments using data from the Bureau of Economic Analysis and the U.S. Census.¹⁹ Finally, 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-shock 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 they own.

The estimated parameters as well as the empirical targets and their model counterparts are reported in Table 4. We find that the seven estimated parameters can be chosen to match the seven targets exactly. To have lower net exports of essential goods than non-essential goods, the model requires producers of non-essentials to be more productive than producers of essential goods. The model also 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 shocks We estimate the remaining parameters to match salient features of the dynamics of the U.S. economy following the onset of the shocks: the elasticity of substitution ρ between essential and non-essential goods, the capital and labor adjustment costs $\{\Omega_{ke}, \Omega_{\ell e}\}$ faced by producers of essential goods, the capital and labor adjustment costs $\{\Omega_{kn}, \Omega_{\ell n}\}$ faced by producers of non-essential goods, and the bond-holding costs Ω_b . We simplify the estimation by assuming that $\Omega_{ke} = \Omega_{\ell e}$ and $\Omega_{kn} = \Omega_{\ell n}$.

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 the aggregate net exports to GDP ratio. All moments are computed as the average monthly change throughout Q2 and

gated to distinguish between personal protective equipment and other medical goods.

¹⁸Thus, our empirical counterpart to GDP in the model is U.S. goods GDP.

¹⁹International 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 5: Estimated parameters, post-shock dynamics

| Parameter | Value | Description | |
|--|--------|--|--------|
| ρ | 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 | |
| Ω_b | 0.024 | Bond-holding cost | |
| Moment | | Target value | Model |
| e_t : log(Avg. Q2-Q3 '20 / Pre-pandemic) | | 0.619 | 0.663 |
| c_t : log(Avg. Q2-Q3 '20 / Pre-pandemic) | | −0.062 | −0.062 |
| $y_{c,t}$: log(Avg. Q2-Q3 '20 / Pre-pandemic) | | −0.070 | −0.070 |
| NX/GDP : Avg. Q2-Q3 '20 − Pre-pandemic | | −0.009 | −0.009 |

Q3 of 2020 relative to Q4 of 2019.²⁰

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.²¹ Table 5 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. Finally, we estimate bond-holding costs equal to 0.024.

²⁰The only exception is moment (*i*), which is computed relative to January 2020 due to data availability.

²¹We study the perfect foresight solution of the model numerically using global methods.

4.4 Dynamics following shortages of essential goods

We now study the impact of a global demand shock by computing impulse response functions following the shocks presented in Figure 3. The dynamics of key variables, expressed as percent deviations from their steady-state values, are presented in Figures 4 and 5.²² We restrict attention to the dynamics over the first two years (24 periods) following the onset of the shocks.

Production and trade of essential goods We begin with the dynamics of production and trade of essential goods, illustrated in Figure 4. 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.

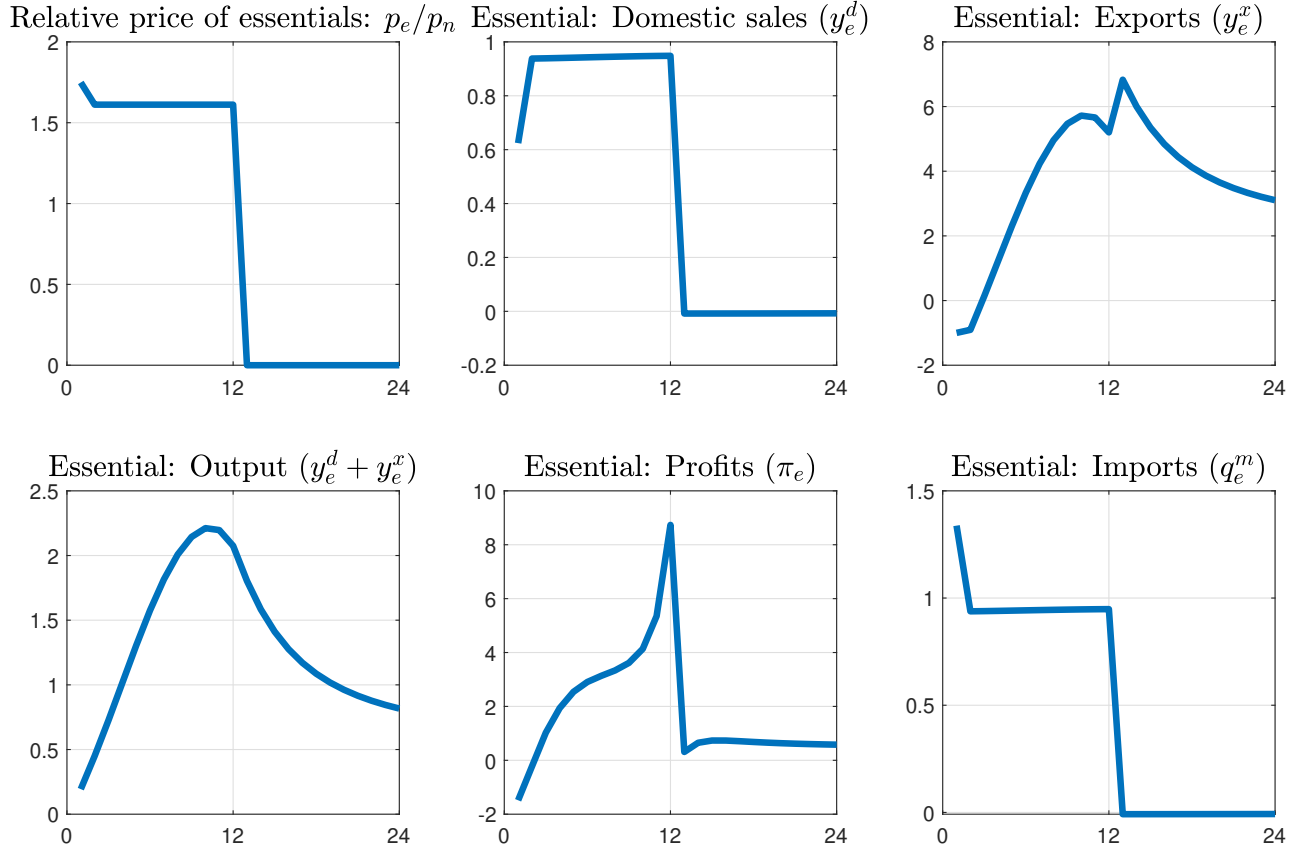
These higher prices of essential goods increase the returns to accumulating capital and hiring labor for producers of essential goods, rising the optimal production scale — as described in Section 3.2. However, production increases gradually given the costs to adjust capital and labor. This adjustment of production 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 — as described in Section 3.1. 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, 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

²²We report the dynamics of a broader set of variables in the Online Appendix.

Figure 4: Dynamics of 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.

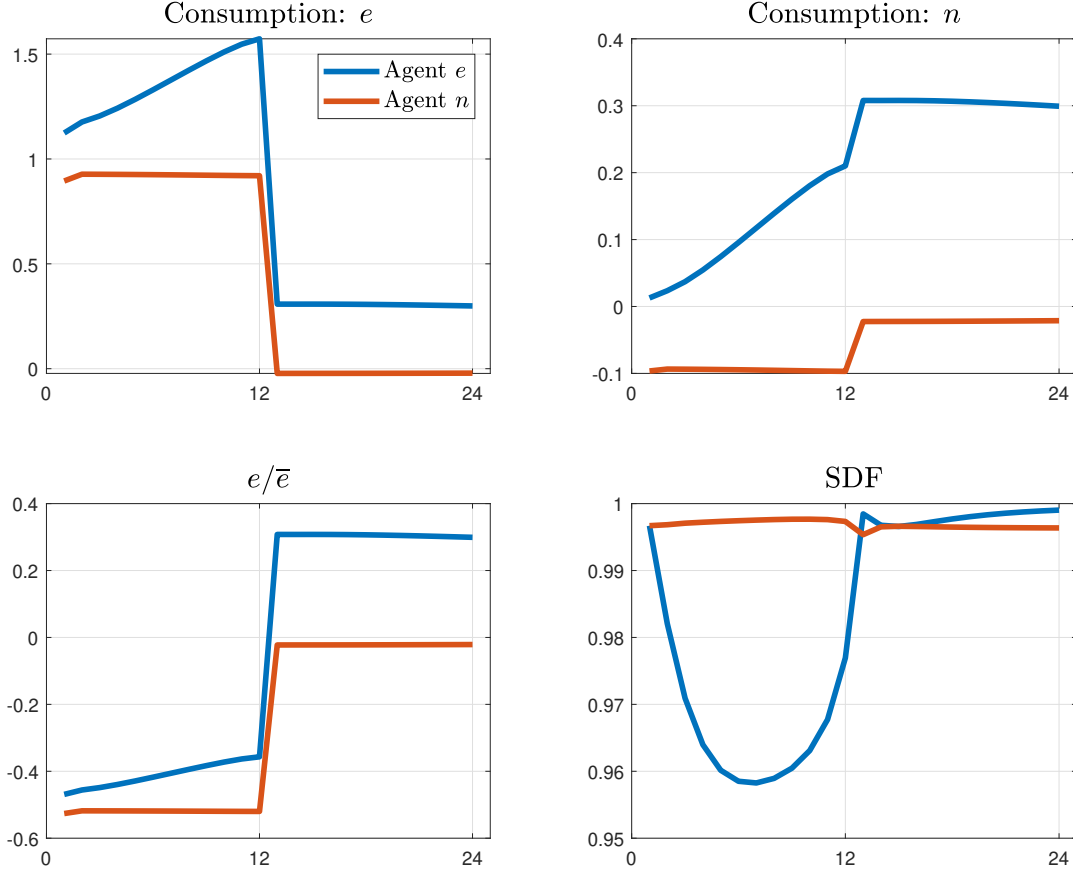
goods? We study these and other related questions in Section 5.

Consumption and discounting Given our setup with heterogeneous households and incomplete markets, the consumption and discounting dynamics implied by the model differ between them, as described in Section 3.2. Figure 5 plots key variables on the dynamics of consumption and discounting for households of each type.

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 the 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 types of goods, while households of type n increase their consumption of essential goods but reduce their non-essential

Figure 5: Dynamics of 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.

consumption. This contrast in consumption dynamics is accounted by the divergent economic impact of the pandemic across household types. 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 households from borrowing 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 reduces the SDF.

Differences in discounting across households are also critical to determine investment and hiring decisions of the firms they own. 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, as described in Section 3.2. 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 trade and industrial policy interventions that increase welfare? We study these and other related questions in the next section.

5 Optimal trade and industrial policy following shocks

We now ask: To what extent would it be optimal to introduce international trade or industrial policies on essential goods following the shocks?

To answer this question, we endow the government with three policy instruments targeted only on essential goods: (i) ad-valorem import tariffs τ_{et}^m , (ii) ad-valorem export taxes τ_{et}^x , and (iii) ad-valorem sales subsidies τ_{et}^y .²³ We refer to (i) and (ii) as trade policies, and to (iii) as industrial policy. While trade policies are designed to alter the incentives to sell and source essential goods domestically or internationally, industrial policies are designed to alter the incentives to produce essential goods. Note that negative values of τ_{et}^m and τ_{et}^x denote subsidies, while negative values of τ_{et}^y denote taxes. To simplify the analysis, we restrict attention to one-time transitory changes to (i) – (iii), which become active during the pandemic, 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 design the financing and reimbursement of these policy instruments across households. As in Itskhoki and Moll (2019), we do not allow for direct transfers of resources across households. In particular, we assume

²³We keep $\tau_{nt}^m = \tau_{nt}^x = \tau_{nt}^y = 0$ throughout.

that (i) revenues from import tariffs on essential goods are rebated back to households in proportion to the share of total imports consumed (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 the 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 the households that own essential goods producers (that is, $\psi_{eet}^y = 1$ and $\psi_{net}^y = 0$). These constraints prevent the government, for instance, from choosing to tax exports of the firm owned by household e to rebate the tax revenues to household n .

Finally, we focus on a standard utilitarian government objective function whose value in period t consists of the population-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:

$$\mathcal{V}_t = \lambda_n V_{nt} + \lambda_e V_{et},$$

where λ_n and λ_e denote the respective population shares of each household type.

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.

To isolate the role of the distortions discussed in Section 3 on the optimal policies, we abstract from terms of trade effects by removing markup distortions due to monopolistic competition by introducing a constant domestic sales subsidy as in Galí and Monacelli (2005). This implies that the optimal trade and industrial policies in the pre-shock steady state are all zero (see Tables 8 and 9).

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.²⁴ Table 6 reports the optimal policy rates for each of these cases.

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, along with a 9.44% subsidy on imports of these goods.²⁵ 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 shocks. 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 to increase the production and consumption of essential goods. We now examine the potential to jointly introduce trade and industrial policies. The third row of Table 6 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 policies are larger when introduced jointly.²⁶ In the Online Appendix we show that these findings are robust under a number of alternative specifications of the model and approaches to quantifying it.

Our findings raise numerous questions on the impact of these policies and the channels that account for the optimal policy response to shortages of critical goods. We address these questions in three ways. First, we examine the welfare gains from these policies. Second, we investigate their impact on equilibrium outcomes. Finally, we study the role played by various features of the model in accounting for our findings.

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. For each alternative set of policy instruments, we compute the welfare gains in consumption-equivalent units between an economy without policy

²⁴To 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 $\tau_e^m = \tau_e^x = 0$.

²⁵These findings are consistent with Lerner's symmetry given we restrict attention to trade policies on a subset of goods — i.e., essential goods. In the Online Appendix we report the optimal policies when the government is endowed with only one trade policy instrument at a time.

²⁶In the Online Appendix, we report the optimal policies in response to each of the shocks one at a time.

Table 6: Optimal policies following shocks

| | Export tax | Import tariff | Total sales subsidy | Welfare gain |
|-----------------------------|------------|---------------|---------------------|--------------|
| Trade policy | 14.26% | −9.44% | — | 0.24% |
| Industrial policy | — | — | 12.23% | 0.09% |
| Trade and industrial policy | 25.02% | −18.28% | 27.97% | 0.72% |

interventions vs. an economy with optimal policy changes. Specifically, we ask: What uniform percentage increase of the consumption bundle of every household over the duration of the shocks would make the government indifferent between an economy with vs. without optimal policy changes?

To answer this question, we solve for the value of α 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 $\frac{[(1+\alpha)c]^{1-\xi}}{1-\xi}$ for the duration of the shocks, with (ii) the value of the government’s objective function in period 1 under the optimal policies. Thus, the welfare gains are measured based on a proportional increase of consumption throughout the 12 periods that the shocks and policies last for. The last column of Table 6 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 are equal to 0.24% in consumption-equivalent units. That is, households in an economy without policy changes would need their consumption bundle to increase by 0.24% every period for the duration of the shocks to be indifferent to living in the economy that implements the optimal trade policies during the pandemic. The gains are quantitatively significant: They are at least an order of magnitude larger than the welfare cost of business cycles (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: 0.09% vs. 0.24%, 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 0.72%, 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 equilibrium dynamics following the shocks. 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 6. We find that the optimal trade policy allows households to increase their consumption of essential goods throughout the duration of the shocks relative to the economy without trade policy changes. Notice, however, that consumption of these goods remains substantially below the reference level even under the optimal trade policy.

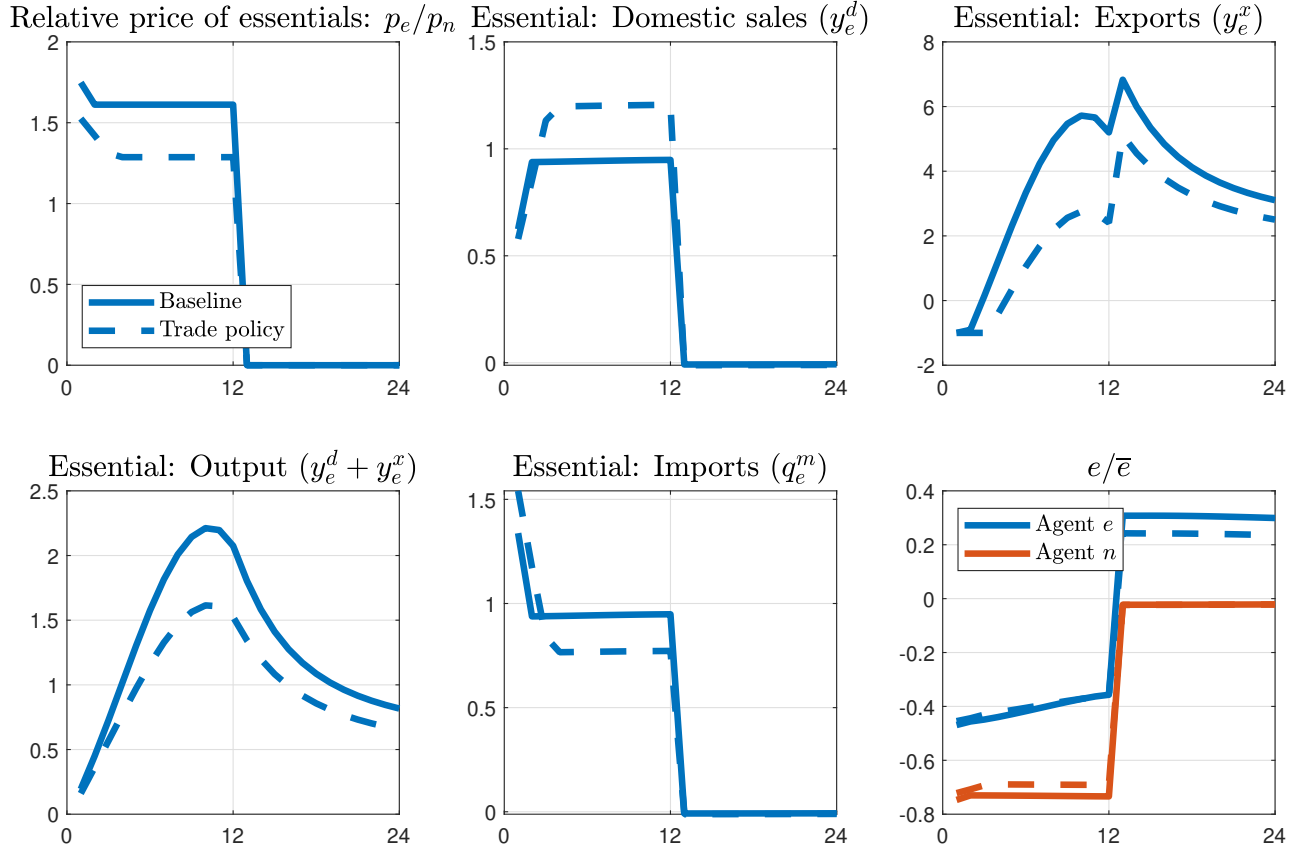
The tax on exports leads firms to lower the domestic price of essential goods. While this discourages production of essential goods, slowing down the increase of output, it leads to a reallocation of sales from exports to domestic consumers. Thus, domestic sales increase relatively more than under the baseline, while exports decline substantially. Thus, optimal export taxes result from balancing two conflicting forces: They reduce the incentives to produce essential goods, 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.²⁷ This allows households to purchase imports of essential goods at a lower price, increasing imports and total consumption of these goods. Thus, we find that export taxes and import subsidies increase domestic and imported consumption of essential goods, mitigating the negative impact of the increase in the reference level \bar{e} .

Optimal industrial policy We now examine the impact of the optimal industrial policy, presented in Figure 7. 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: Consumption of these goods declines for households of type e , experiencing a very modest increase across households of type n .

²⁷In the Online Appendix, we show that there is no role for import subsidies when introduced in isolation.

Figure 6: Dynamics under optimal trade policy

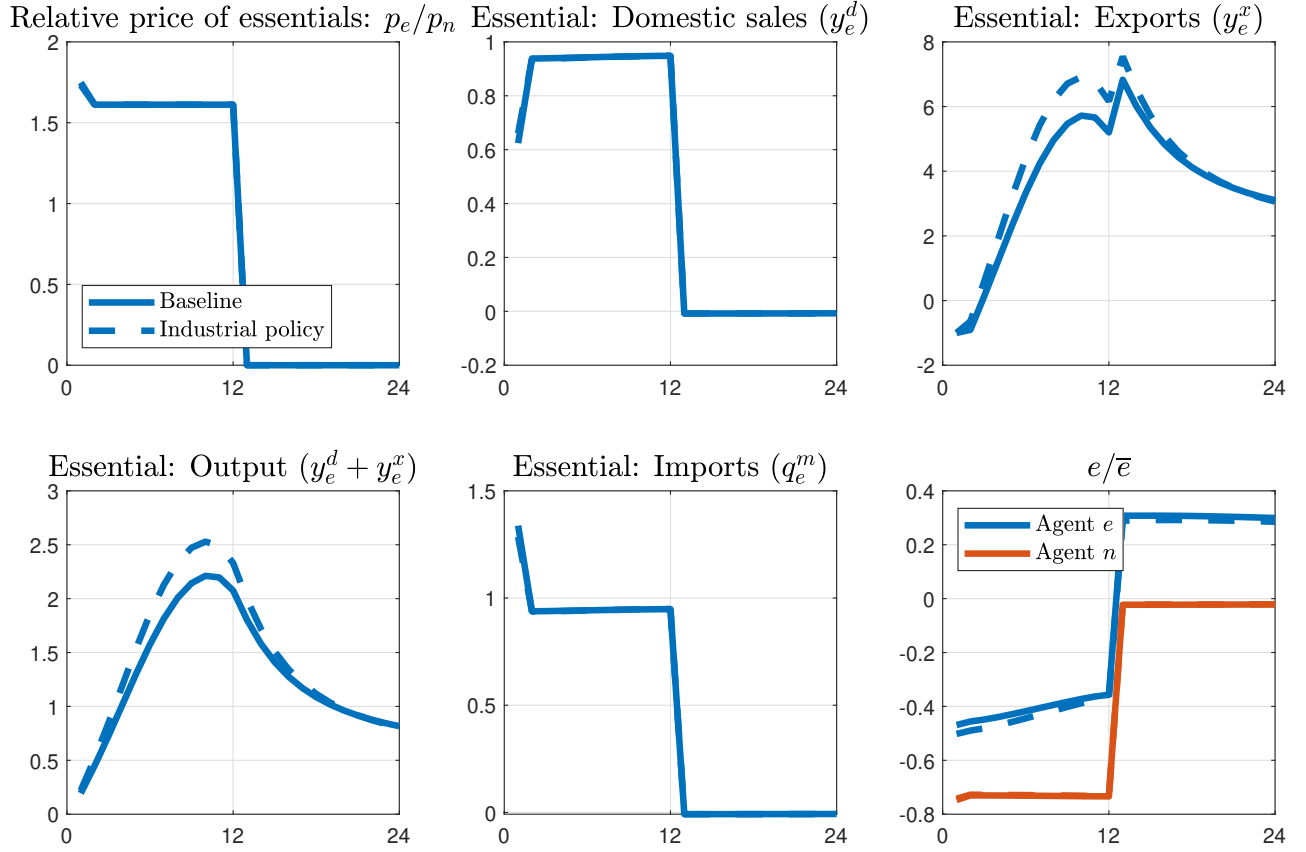


Note: The x -axes denote time periods (months). The y -axes are expressed as percent deviations from steady state. Specifically, percent changes are obtained by multiplying the values in the panel by 100.

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 primarily exported rather than sold domestically. Given the price of essential goods is determined internationally, it largely pins 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 the shocks. The optimality of international trade policy is primarily accounted by an intra-temporal motive, reallocating production across markets at the expense of discouraging investments to increase production. In contrast, the optimality of industrial policy is primarily accounted by an inter-temporal motive that leads to increased production without consideration for the

Figure 7: Dynamics under optimal industrial policy

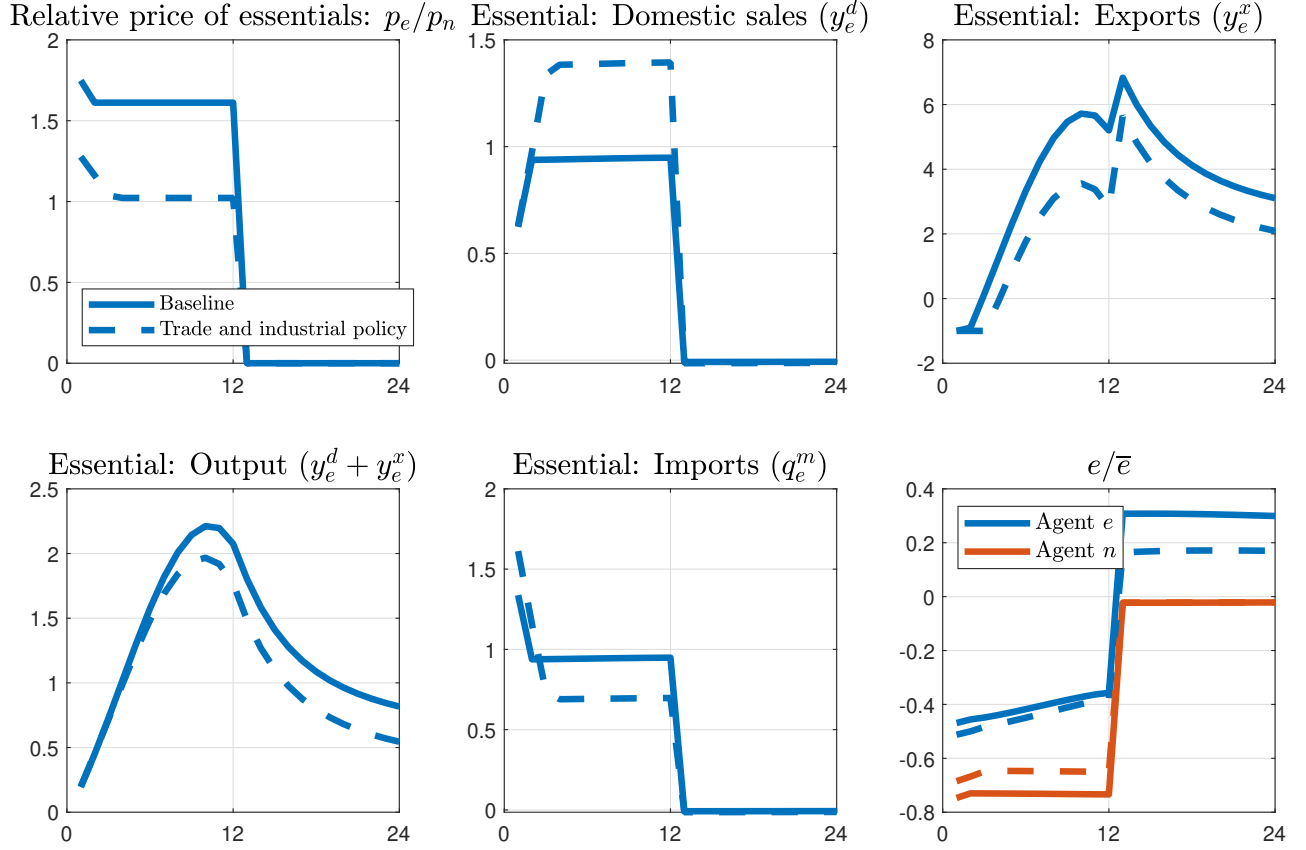


Note: The x -axes denote time periods (months). The y -axes are expressed as percent deviations from steady state. Specifically, percent changes are obtained by multiplying the values in the panel by 100.

destination of the additional goods produced. The welfare results show that these policies are complementary following the shocks that we study — thus, we now investigate their joint impact, presented in Figure 8.

We find that, indeed, 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 incentives to increase production, trade policy 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.

Figure 8: 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.

5.4 Efficiency vs. redistribution

We now investigate the relative importance of efficiency vs. redistributive considerations in accounting for our findings. The set of policies that we study act by affecting firms' production decisions, without resorting to the *direct* redistribution of resources. However, these policies may nevertheless increase social welfare either by increasing the aggregate amount of goods consumed domestically (efficiency), or by changing the relative level of consumption across agents (redistribution).

We decompose the relative importance of these motives in accounting for our optimal policy findings by following Benabou (2002) and Boar and Midrigan (2022). Their approach consists of specifying an alternative social welfare function which nests the standard utilitarian objective, but which is parameterized to span the pure efficiency case on one end, and a Rawlsian objective on the other end. In particular, we solve for the value ω_{it} that solves

the following equation for each household type $i \in \{n, e\}$:

$$\sum_{k=0}^{\infty} \beta^k \frac{\omega_{it}^{1-\xi}}{1-\xi} = V_{it},$$

where ω_{it} is the constant level of consumption that generates the same lifetime utility from period t onwards as the equilibrium consumption path underlying value function V_{it} . Thus, ω_{it} captures the equilibrium level of welfare of household i .

Given constant $\Delta \geq 0$, we define an alternative government's objective function that aggregates household-specific welfare levels ω_{it} :

$$\tilde{\mathcal{V}}_t = \left(\sum_{i \in \{n, e\}} \lambda_i \omega_{it}^{1-\Delta} \right)^{\frac{1}{1-\Delta}},$$

where λ_i weights each household type's welfare level with its corresponding population weight. As in Benabou (2002) and Boar and Midrigan (2022), if $\Delta = \xi$, then we have that $\tilde{\mathcal{V}}_t = \mathcal{V}_t$ — that is, in this case the alternative objective of the government is identical to the utilitarian objective examined in previous subsections. Moreover, if $\Delta > \xi$, the alternative government's objective features a greater redistributive motive than the utilitarian objective — as $\Delta \rightarrow \infty$, the objective approaches a Rawlsian objective. And, conversely, if $\Delta < \xi$, then the alternative government's objective features a greater efficiency motive than the utilitarian objective — $\Delta = 0$ is the pure efficiency case.

To evaluate the relative importance of efficiency vs. redistribution in accounting for our findings, we recompute the optimal policy analysis from previous sections under two alternative government's objective functions: the pure efficiency objective ($\Delta = 0$), and the Rawlsian objective ($\Delta = \infty$).

We report our findings in Table 7. We find that the qualitative role for policy interventions is independent of the redistributive motive: Under an objective that restricts attention to efficiency considerations, the optimal trade and industrial policies are qualitatively identical to those in our baseline. Moreover, we find that the optimal trade and industrial policies are quantitatively similar to those in our baseline: The magnitude of the interventions is approximately 2/3 of our baseline interventions.²⁸ Thus, we conclude that efficiency considerations

²⁸Note that, analogously, the size of the interventions increases relative to the baseline when the government's objective is Rawlsian.

Table 7: Optimal policy, efficiency vs. redistribution

| | Export tax | Import tariff | Total sales subsidy |
|--------------------------------|------------|---------------|---------------------|
| Efficiency ($\Delta = 0$) | 16.65% | −12.42% | 19.51% |
| Baseline ($\Delta = \xi$) | 25.02% | −18.28% | 27.97% |
| Rawlsian ($\Delta = \infty$) | 65.20% | −29.62% | 40.16% |

account for 2/3 of the policy interventions that we find, while redistributive considerations account for the rest.

5.5 Key channels

We conclude this section by investigating the key features of the model that account for the optimality of trade and industrial policies in response to the shocks that we study. Tables 8 and 9 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 steady-state targets (Table 4) but keeping the parameters that discipline the dynamics as in the baseline (Table 5).

No shocks The second row of each table reports the optimal policies in the absence of shocks — that is, in the steady state of the model. We observe that there is no role for either trade or industrial policy in the steady state. 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 is abstracting from terms of trade effects by removing markup distortions due to monopolistic competition (Gali and Monacelli 2005).

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 distortions that we study 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 discount rate. In contrast, in an economy without household heterogeneity, all households and firms discount the future at the same rate despite incomplete markets.

Table 8: Key channels underlying optimal trade policy

| | Export tax | Import tariff |
|---|------------|---------------|
| Baseline | 14.26% | −9.44% |
| No shocks (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% |

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 ξ implies a higher inter-temporal elasticity of substitution, so households find it easier to reduce consumption during the shocks in exchange for higher consumption afterwards. Thus, the government finds it optimal to avoid the costs involved with adjusting production decisions to increase consumption of essential goods.

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 more easily substitute essential with non-essential goods, sidestepping the increased need for essential goods and higher prices.

In contrast, we find that the optimal industrial policy is not significantly affected by 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. Thus, industrial policy is effective in this case since it primarily affects firms' inter-temporal decisions, without much impact on intra-temporal ones.

Table 9: Key channels underlying optimal industrial policy

| | Total sales subsidy |
|---|---------------------|
| Baseline | 12.23% |
| No shocks (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% |

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. Consistent with the discussion in Section 3, we find the optimal policy response is larger with more limited access to financial markets.

6 Evidence: Trade and industrial policies during shortages of critical goods

The findings reported in the previous section show that trade and industrial policies can be an effective way to address shortages of critical goods in an open economy. Figure 1 in the introduction shows that these policies have indeed been implemented in recent episodes following shortages of critical goods. In this section, we investigate whether the likelihood of these responses depends on the extent that countries depend on trade to access the respective goods. To do so, we focus on the case of essential medical goods following COVID-19.

We use data from Global Trade Alert on trade and industrial policy interventions by country and product categories. In contrast to Figure 1, we follow the approach of the

previous sections and restrict attention to PPE that was critical at the onset of the COVID-19 pandemic. In particular, we restrict our analysis to 16 PPE-related products demanded during COVID-19, as classified by the World Trade Organization (WTO).²⁹ We use these data to document the evolution of 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 2019.³⁰

Figure 9 plots the number of country-product pairs 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. By the end of April 2020, 279 country-product pairs were subject to newly introduced export restrictions, 779 had experienced a liberalization of import barriers, and 51 were subject to industrial policies. While trade policy interventions were mostly temporary, many were still in place a year into the pandemic. 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, going from 51 in April 2020 to 106 in January 2021.

Trade policy To examine how trade policy varies with trade dependence, we measure the latter based on product-level trade imbalances. We classify country-product pairs into two groups based on their trade imbalance in 2019 using data from CEPII: country-pairs with a trade deficit and those with a surplus.³¹ For each group, Figure 10 plots the share of country-product pairs with export restrictions and import liberalizations.

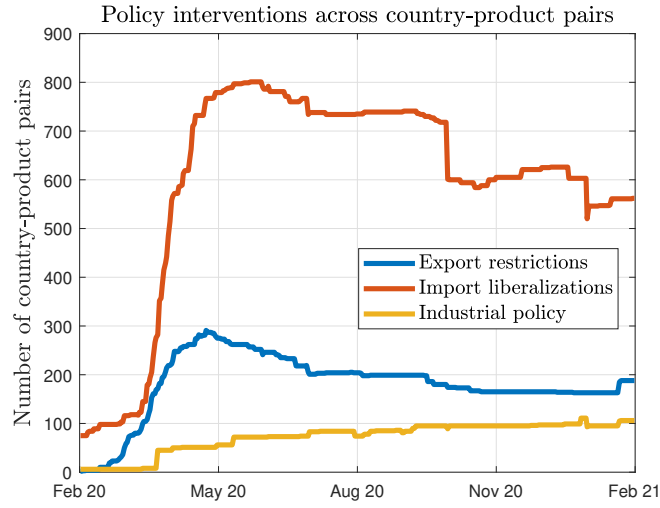
We find that country-product pairs with trade deficits prior to the pandemic were more likely subject to trade policy interventions. On the one hand, country-product pairs with a

²⁹See 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.

³⁰We 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 consist 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.

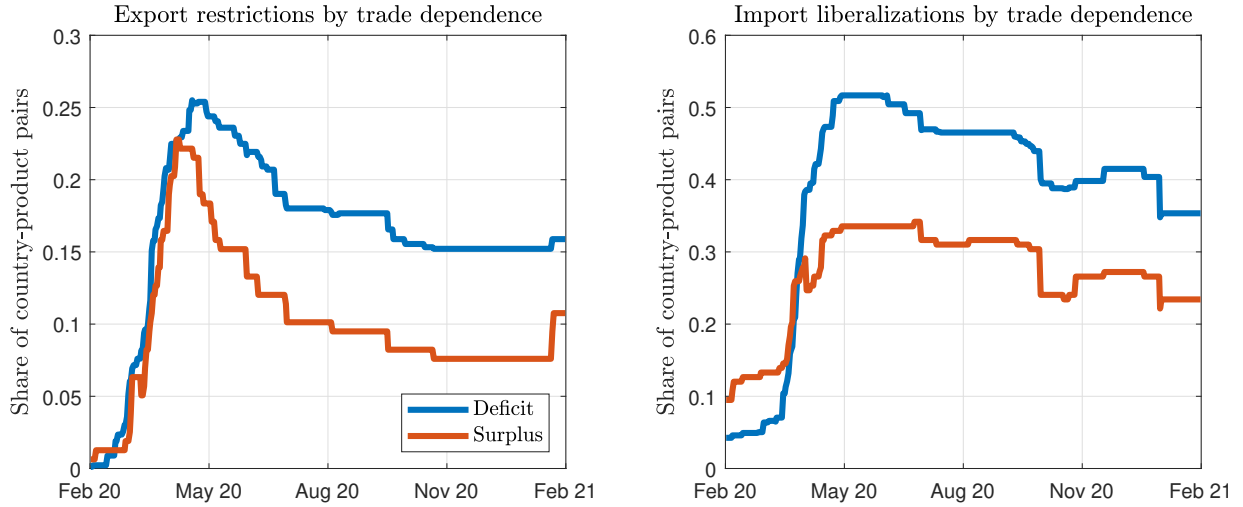
³¹http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele.asp.

Figure 9: Policy interventions following shortages of PPE 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.

Figure 10: Trade 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.

deficit were more likely to liberalize import barriers. In contrast, the likelihood of introducing export restrictions during the first months of the pandemic was largely independent of trade dependence. Export restrictions, however, were removed faster among country-product pairs with a trade surplus, suggesting that countries with a comparative advantage in these

Table 10: 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% |

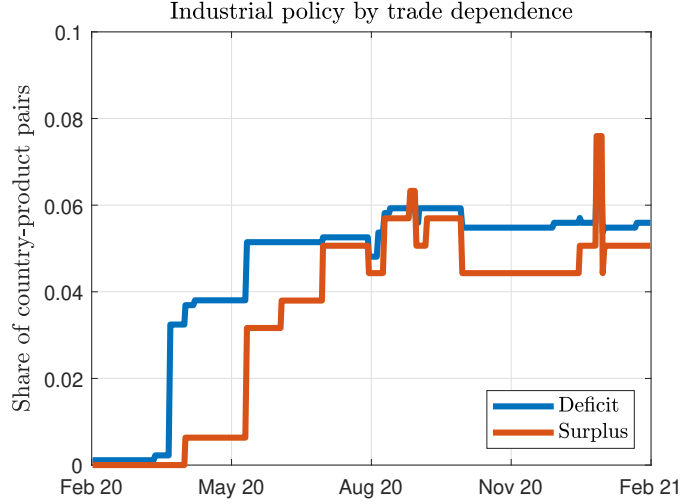
products were better equipped to scale up production in the face of global shortages.

To contrast 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 with alternative degrees of international trade dependence on essential goods. In particular, we keep the parameters from Table 5 as in the baseline, and we recalibrate the parameters from Table 4 targeting a net exports-to-GDP ratio in essential goods equal to ± 0.30 .

We report our findings in Table 10. As in the data, both sets of countries find it optimal to introduce policies that restrict exports and liberalize imports. Moreover, 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. Countries with a trade deficit of essential goods are more dependent on the rest of the world to access these goods and, thus, are more negatively affected by their price increase. Thus, these countries have a greater incentive to reallocate exports and increase imports. We interpret these differences as consistent with the evidence documented above: Economies with larger deficits of essential goods respond more strongly to shortages of these goods.

Industrial policy We conclude by examining the extent to which optimal industrial policy interventions vary with trade dependence. Figure 11 plots the share of country-product pairs subject to industrial policy interventions across countries with a deficit or surplus of essential goods prior to the pandemic. We find there is minimal variation in the likelihood of introducing industrial policy measures across these two sets of country-product pairs. Consistent with this evidence, Table 11 shows that the extent of the industrial policy interventions implied by the model are also largely independent of the extent of trade dependence. In both economies the higher price of exports makes it attractive to increase sales regardless of their net reliance on the rest of the world to access essential goods.

Figure 11: Industrial 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.

Table 11: Optimal industrial policy and sectoral imbalances

| | Total sales subsidy |
|---|---------------------|
| Trade deficit of essential goods ($NX_e/GDP_e = -0.30$) | 12.36% |
| Trade surplus of essential goods ($NX_e/GDP_e = 0.30$) | 13.83% |

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 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 following recent episodes of shortages of critical goods.

Our findings raise questions about the potential to identify multilateral trade policy solutions. In addition, the analysis of policy design ex-post and our focus on trade and industrial policy limits the set of instruments that we examine. Further analysis on multilateral trade agreements, ex-ante policies, and other policy instruments (e.g., credit policies, consumption

taxes, profit taxes) are a fruitful area for future research.

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