Shortages of Critical Goods in a Global Economy: Optimal Trade and Industrial Policy[1]

Appendix for Online Publication

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[1]The views expressed in this paper are those of the individual authors and do not necessarily reflect official positions of the Federal Reserve Bank of St. Louis, the Federal Reserve System, or the Board of Governors.

Appendix A: Data sources

This appendix describes the main data sources used throughout the paper.

COVID-19 products The classification of COVID-19 related products is from Annex 1 of the following document created by the World Trade Organization (WTO): `https://www.wto.org/english/news_e/news20_e/rese_03apr20_e.pdf`. The list of 6-digit HS codes is: 340220, 401519, 621010, 630790, 650500, 650610, 842139, 900490, 901812, 901819, 901839, 901920, 902000, 902212, 902214, 902519.

Policy interventions Data on trade policy interventions are from Global Trade Alert: `https://www.globaltradealert.org/`. We restrict our attention to policy interventions that involve export restrictions (imposing export bans, licensing requirements, taxes, quotas, and non-tariff measures), import liberalizations (reducing import tariffs, licensing requirements, quotas, bans and non-tariff measures), and industrial policy (financial grants, state aid, state loans, loan guarantees, production subsidies, capital injections). We use data from February 2020 and January 2021.

Specifically, we group the policy interventions reported in the original dataset into the three groups that we study as follows. Export restrictions consist of the tightening or introduction of any of the following policies: export tax, local supply requirement for exports, export licensing requirement, export ban. Import liberalizations consist of the relaxation of any of the following policies: import tariff quota, import tariff, import licensing requirement, internal taxation of imports, import quota, import-related non-tariff measure. Industrial policies 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, localization incentive, price stabilization, in-kind grant, capital injection and equity.

Sectoral output Domestic gross output and value added and gross output data by industry are collected from the Bureau of Economic Analysis (BEA), GDP by industry: `https://www.bea.gov/data/gdp/gdp-industry`. We use data for the year 2019. Medical goods correspond to the categories "Medical equipment and supplies manufacturing" and "Pharmaceutical and medicine manufacturing."

International trade flows Monthly data on imports and exports of medical goods (values and unit prices) are from the US Census, USA Trade Online: `https://usatrade.census.gov/`.

Production and demand for COVID-19 goods Data on demand and production (domestic and imports) are from estimates computed by the White House Task Force. The projections were created by the White House Supply Chain Task Force, released by Democratic Sen. Maggie Hassan's office: `https://www.hassan.senate.gov/imo/media/doc/SCTF%20Demand%20PPE%20Chart.pdf`

Appendix B: Additional evidence on the role of financial constraints

This appendix presents additional empirical evidence on the importance of financial frictions during shortages of essential goods. To do so, we document the prevalence of government policies designed to mitigate financial constraints during the COVID-19 pandemic. The widespread adoption of these policies highlights financial constraints as a significant obstacle to scaling production during crises.

1 Cross-Country evidence

To investigate the role of financial-oriented industrial policy interventions during the COVID-19 pandemic, we analyze data from the New Industrial Policy Observatory 2.0 (NIPO 2.0), which tracks industrial policies related to medical products across 76 jurisdictions worldwide. This comprehensive dataset enables us to document the extent to which governments implemented industrial policies aimed at alleviating financial constraints faced by producers of essential goods.

We categorize industrial policy measures into three distinct groups:

1. *Financial policies*, which directly address liquidity and credit constraints faced by firms. These include capital injections, equity stakes, interest payment subsidies, loan guarantees, state loans, and other forms of financial assistance.
2. *Procurement policies*, which focus on reducing demand risk through purchase guarantees and grants.
3. *Other policies*, which support production through alternative channels.

Table 1 presents the distribution of these policies across OECD countries during 2020-2022. Financially-driven industrial policies constituted 46.8% of all interventions in OECD countries, compared to 32.0% for demand-oriented policies. The prevalence of financial support mechanisms was particularly notable in certain countries, such as Canada (75.7%) and Germany (66.7%), suggesting that addressing financial constraints was a central policy concern during the pandemic preventing firms from scaling up production.

	OECD		USA		CAN	
Policy	Number	%	Number	%	Number	%
Financial	336	46.8	45	27.11	56	75.68
Demand	230	32.03	42	25.3	3	4.05
Other	152	21.17	79	47.59	15	20.27
	EU		GER		UK	
Policy	Number	%	Number	%	Number	%
Financial	25	60.98	22	66.67	8	34.78
Demand	7	17.07	9	27.27	13	56.52
Other	9	21.95	2	6.06	2	8.70

Table 1: Number of policies, regulations, and firm-specific interventions

The prevalence of financial industrial policies is particularly striking given the advanced financial markets characteristic of OECD countries. Even in these economies, governments found it necessary to intervene extensively through financial channels to support the production of essential medical goods. This pattern underscores the significance of financial constraints in shaping responses to shocks affecting the demand for essential goods.

Table 2 further illustrates the widespread nature of financial industrial policy interventions: 76.7% of OECD countries adopted at least one industrial policy—such as direct loans, loan guarantees, or bond purchases—to ease liquidity and credit constraints and support the production of medical products during the pandemic. The broad adoption of financial support policies across diverse institutional and financial frameworks highlights the significance of financial frictions as an important constraint on scaling up production during the crisis.

Category	Number	Share of OECD Countries (%)
Financial	23	76.67
Demand	23	76.67
Other	18	60.00

Table 2: Number of countries with at least one policy or firm-specific intervention

1.1 U.S. evidence

To provide further evidence on the role of financial frictions, we examine detailed data from the United States. Specifically, we document how multiple U.S. government agencies implemented financial measures to address liquidity and credit constraints faced by producers of essential medical goods during the COVID-19 pandemic.

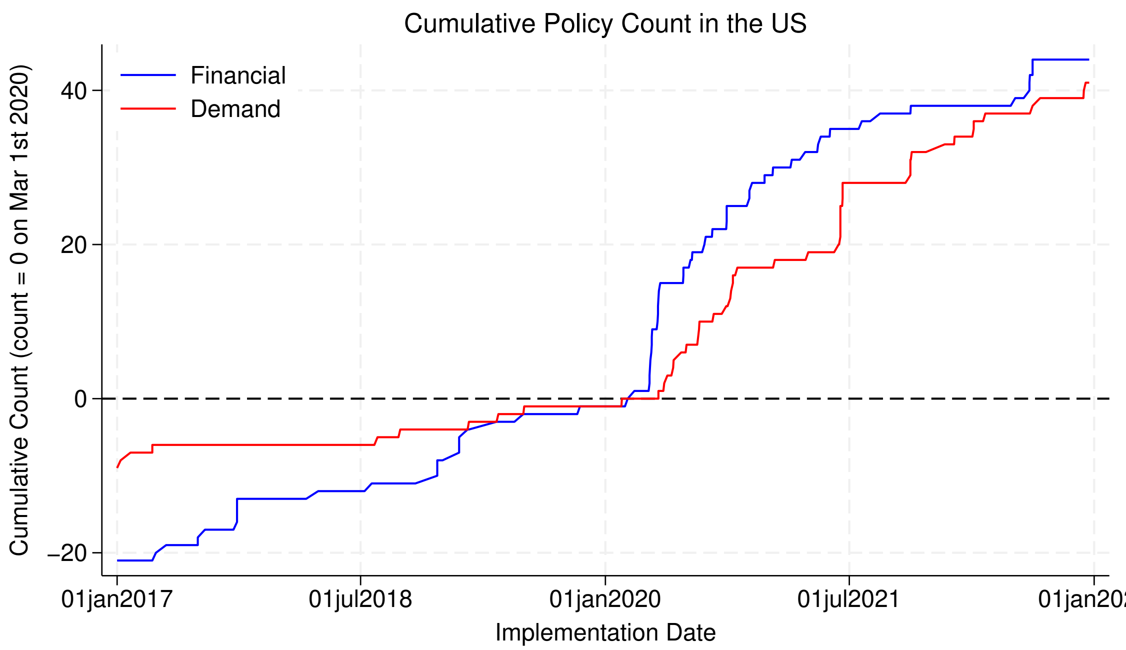


Figure 1: Cumulative Policy Count in the U.S.

Figure 1 shows the cumulative implementation of different types of policies in the United States during the COVID-19 pandemic. The substantial growth in financial support policies over time indicates that policymakers recognized the importance of addressing financial constraints to ensure adequate production of essential goods.

The following specific cases illustrate how firms received financial support to address constraints during the pandemic:

1. **Ology Bioservices Inc.** received a $25 million loan through the Federal Reserve's Main Street Lending Program, with the Fed purchasing 95% of the loan to mitigate risk for the originating bank. Favorable terms, including deferred principal and interest payments, addressed immediate liquidity constraints, enabling the firm to scale production.
2. **Pfizer Inc.** benefited from $32 million in Federal Reserve bond purchases via the Secondary Market Corporate Credit Facility. This intervention provided market liquidity to support operations of a key pharmaceutical company involved in vaccine development.

3. **Ginkgo Bioworks, Inc.** secured a $1.1 billion loan from the U.S. International Development Finance Corporation to facilitate mass production of key vaccine raw materials and expand COVID-19 testing capacity. This directly addressed production constraints that were challenging to overcome through private financing alone.
4. **Dendreon Pharmaceuticals LLC** obtained a $10 million Payment Protection Program loan, later forgiven, effectively providing grant funding to maintain operations. This example highlights how liquidity constraints impacted even established pharmaceutical firms.

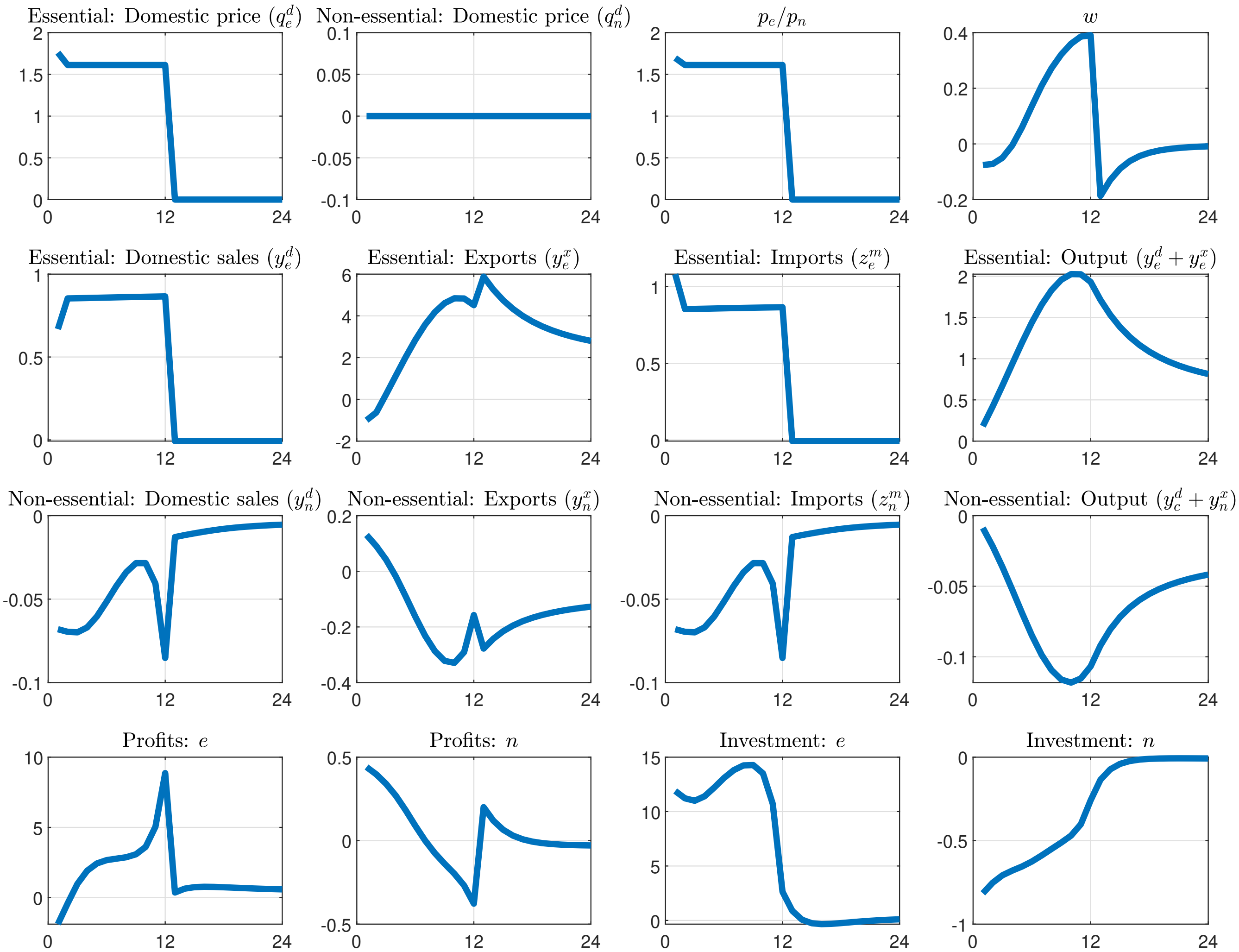
These examples illustrate the diverse ways financial constraints affected firms, necessitating tailored interventions to ensure continued and expanded production of essential goods. In some cases, firms required direct loans to finance production expansion (e.g., Ginkgo Bioworks), while in others, support for market liquidity was crucial to maintain ongoing operations (e.g., Pfizer). The variety of financial interventions underscores how financial frictions can impede production responses during crises.

Appendix C: Additional quantitative findings

This appendix presents additional findings that complement those presented in the paper.

2 Impulse response functions

Figure 2 displays impulse response functions for additional variables that complement those presented in the paper. The shocks considered here are identical to those described in the main analysis; we focus specifically on the dynamics under the scenario without policy interventions.



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.

Figure 2: Impulse response functions, additional variables

3 Key channels

In this section, we investigate 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 3 and 4 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,

Table 3: Key channels underlying optimal trade policy

	Export tax	Import tariff
Baseline	13.61%	−9.33%
No shocks (steady state)	0.00%	0.00%
No household heterogeneity (representative household)	0.10%	0.08%
Weaker inter-temporal complementarity ($\xi = 0.50$ vs. $\xi = 2$)	− 1.30%	1.07%
Weaker intra-temporal complementarity ($\rho = 0.80$ vs. $\rho = 0.29$)	− 0.65%	0.45%
Lower adjustment costs ($\Omega_{k,e} = \Omega_{\ell,e} = 0$)	7.27%	− 4.48%
Higher adjustment costs ($\Omega_{k,e} = \Omega_{\ell,e} = 100$)	18.07%	−26.61%
Lower interest rate sensitivity ($\Omega_r = 0.00001$)	3.36%	−2.65%
Higher interest rate sensitivity ($\Omega_r = 1$)	15.91%	−10.08%
Financial autarky	25.42%	−15.16%

recalibrating the model to match the steady-state targets but keeping the parameters that discipline the dynamics as in the baseline.

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 quantitatively significant role for either trade or industrial policies in the absence of household heterogeneity.

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 $\rho = 0.29$). 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.

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

Table 4: Key channels underlying optimal industrial policy

	Total sales subsidy
Baseline	16.86%
No shocks (steady state)	0.00%
No household heterogeneity (representative household)	0.11%
Weaker inter-temporal complementarity ($\xi = 0.50$ vs. $\xi = 2$)	4.76%
Weaker intra-temporal complementarity ($\rho = 0.80$ vs. $\rho = 0.29$)	16.11%
Lower adjustment costs ($\Omega_{k,e} = \Omega_{\ell,e} = 0$)	20.54%
Higher adjustment costs ($\Omega_{k,e} = \Omega_{\ell,e} = 100$)	21.64%
Lower interest rate sensitivity ($\Omega_r = 0.00001$)	6.84%
Higher interest rate sensitivity ($\Omega_r = 1$)	13.32%
Financial autarky (no bond)	29.52%

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.

Interest rate sensitivity The eighth and ninth rows of Tables 3 and 4 report optimal policies under alternative degrees of sensitivity to interest rates. We find that higher interest rate sensitivity ($\Omega_r = 1$) increases the magnitude of optimal trade and industrial policies compared to the baseline, as firms' investment and production decisions become more responsive to financial conditions. Conversely, lower sensitivity to interest rates ($\Omega_r = 0.00001$) results in smaller optimal policy interventions, reflecting the diminished impact of financial conditions on firms' inter-temporal decisions. These findings highlight the important role that firms' sensitivity to financing costs plays in shaping the optimal policy response to demand shocks.

Incomplete markets Finally, the tenth row of each table reports the optimal policies in an economy under financial autarky. We find the optimal policy response is larger with more limited access to financial markets.

4 Optimal policy

4.1 One instrument at a time

Table 5 reports the optimal policy interventions under alternative policy mixes to those considered in the paper. The first row reports the optimal policy intervention when only an export tax is available to the government. The second row reports the optimal policy interventions when only an import tariff is available to the government.

We find there is no role for the introduction of import tariffs in the absence of export taxes. This suggests that, while export taxes improve welfare by reallocating sales from exports toward domestic sales, import tariffs are introduced to mitigate other distortions generated by this reallocation. In particular, export taxes reallocate sales from exports toward domestic sales by reducing the price of domestic essential goods, which increases demand for domestic essential goods relative to imported ones. As described in the paper, it is then optimal to introduce an import subsidy to mitigate this reallocation of demand.

	Export tax	Import tariff	Total sales subsidy
Only export tax	9.67%	–	–
Only import tariff	–	0.00%	–

Table 5: Optimal policy, one instrument at a time

4.2 One shock at a time

Table 6 reports the optimal policy interventions when introduced in response to a counterfactual scenario in which the economy faces each of the shocks in isolation rather than jointly. We restrict attention here to the case in which the government has access to both trade and industrial policy instruments. The first row reports the optimal policies when the economy only faces an increase in the reference level of essential goods. The second row reports the optimal policies when the economy only faces an increase in the price of imports of essential goods. The third row reports the optimal policies when the economy only faces an increase in the price of exports of essential goods.

We find that the optimal policy response to each of tihe shocks in isolaton is identical to the response when the shocks are faced jointly, with one exception. In contrast to the baseline, in response to a shock to the reference level or import prices, it is optimal to introduce an export subsidy rather than an export tax. The reason is that, in this case, the economy faces an increase in the domestic demand for essential goods without an increase in incentives to export. Then, an effective way of increasing the incentives to scale up production of these goods is by subsidizing exports.

	Export tax	Import tariff	Total sales subsidy
Only shock to reference level	-2.19%	-4.39%	8.19%
Only shock to price of imports	-0.89%	-7.87%	12.96%
Only shock to price of exports	15.56%	-6.66%	30.98%

Table 6: Optimal policy, one shock at a time

4.3 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

Table 7: Optimal policy, efficiency vs. redistribution

	Export tax	Import tariff	Total sales subsidy
Efficiency ($\Delta = 0$)	16.43%	−12.38%	22.11%
Baseline ($\Delta = \xi$)	24.94%	−18.96%	32.11%

levels ω_{it}:

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

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 $\widetilde{\mathcal{V}}_t = \mathcal{V}_t$ — 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 $\Delta \to \infty$, 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 an alternative government's objective function: the pure efficiency objective ($\Delta = 0$).

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 very similar to those in our baseline. Thus, we conclude that efficiency considerations account for most of the policy interventions that we find, while redistributive considerations account for the rest.

4.4 Sensitivity analysis

This appendix studies the sensitivity of the findings reported in the paper. Table 8 reports the optimal policies under alternative specifications. We restrict attention here to the case in which the government has access to both trade and industrial policy instruments. The first row of the table reproduces the optimal policies from the baseline analysis reported in the paper.

Rows 2–5 of the table examine the sensitivity of the findings to alternative shocks. Row 2 reports the optimal policies when the economy also experiences a decline of labor supply throughout the pandemic, in addition to the other shocks considered in the baseline. We consider an exogenous 7.8% decline of the aggregate labor endowment throughout the 12 months of the pandemic.[2] Row 3 reports the optimal policies in an economy that experiences a longer pandemic, modeled by considering shocks and policies that last 24 months rather than 12 as in the baseline. Row 4 reports the optimal policies in an economy that experiences a milder pandemic, modeled by considering smaller shocks (1/4 of the baseline). Row 5 reports the optimal policies in an economy that experiences a higher increase in import prices (50% higher than the baseline). We find the optimal policy responses are consistent with those reported in the baseline.

Rows 6–7 examine sensitivity to alternative estimation targets. Row 6 considers an economy recalibrated to match a pre-pandemic steady-state with a lower output share of essential goods (1/2 of the baseline). Row 7 considers an economy with a lower import share of essential goods (30% of absorption). The optimal policies in both cases are nearly identical to the baseline.

[2] We focus on employment (all employees, non-farm), which we obtain from FRED: `https://fred.stlouisfed.org/graph/?g=V1Ss`. We compute the change of employment by comparing average employment between March 2020 and Feb 2021 relative to employment in Feb 2020.

	Export tax	Import tariff	Total sales subsidy
Baseline	24.94%	-18.96%	32.11%
Decline in labor supply (-7.8%)	24.52%	-18.71%	31.03%
Longer pandemic (24 months)	25.87%	-19.20%	42.11%
Milder pandemic (1/4 shock)	7.12%	-6.12%	8.24%
Higher import price increase (1.5x)	60.98%	-16.86%	28.93%
Lower output share of essential goods	27.41%	-20.87%	31.52%
Lower import share of essential goods	25.72%	-18.99%	31.74%
Policy implemented for 6 months	25.16%	-19.09%	36.48%
Policy implemented for 24 months	24.99%	-19.11%	29.62%
Model with workers and capitalists	12.31%	-9.53%	-1.28%
Terms of trade effects	13.95%	−21.26%	—

Table 8: Optimal policy, sensitivity analysis

Rows 8–9 examine sensitivity to the duration of policies. We keep the duration of the shocks as in the baseline (12 months) and vary the duration of policy implementation. Row 8 reports optimal policies when implemented for 6 months; Row 9 reports those implemented for 24 months. In both cases, the optimal policies are nearly identical to the baseline.

Row 10 examines sensitivity to an alternative partitioning of agents. In the baseline, there are two types of agents and two sectors, each agent owning firms in one sector. Here, we consider an alternative where there are workers (endowed only with labor) and capitalists (owning firms in both sectors but no labor). We recalibrate accordingly and find that optimal policy interventions remain similar in this case.

Finally, the last row introduces terms-of-trade considerations by removing the domestic sales subsidy, thereby allowing for markup distortions. In this setting, trade policy becomes relevant even absent shocks. Nonetheless, we find that the incremental change in optimal trade policy due to the shock—an increase of 13.95 percentage points in the export tax and a reduction of 21.26 percentage points in the import tariff—is similar to our baseline.

4.5 Trade and industrial policies by trade dependence: Model vs. data

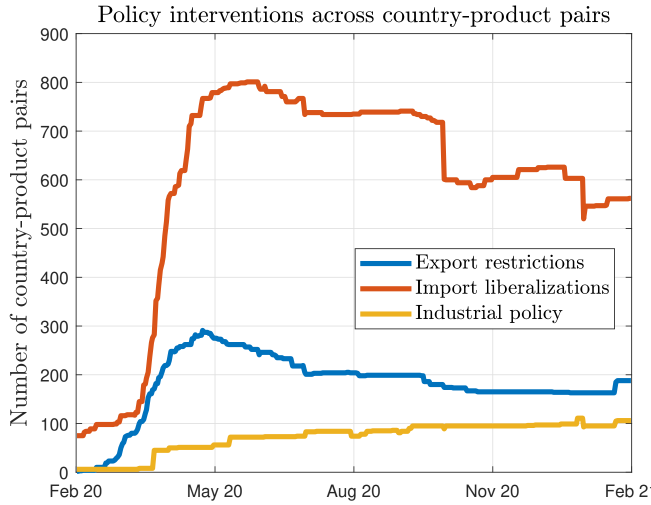
The findings reported in the paper show that trade and industrial policies can be an effective way to address shortages of critical goods in an open economy. In this section, we investigate whether the likelihood of these responses depends on the extent that countries depend on trade to access the respective 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. We 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).[3] 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.[4]

[3] See `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.

[4] We group the policy interventions reported in the original dataset into the three groups that we study as follows. Export restrictions consist of the tightening or introduction of any of the following policies: export tax, local supply requirement for exports, export licensing requirement, export ban. Import liberalizations consist of the relaxation of any of the following policies: import tariff quota, import tariff, import licensing requirement,

Figure 3: **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.

Table 9: Optimal trade policy and sectoral imbalances

	Export tax	Import tariff
Trade deficit of essential goods ($\mathrm{NX}_e/\mathrm{GDP}_e = -0.30$)	14.55%	− 9.77%
Trade surplus of essential goods ($\mathrm{NX}_e/\mathrm{GDP}_e = 0.30$)	8.23%	− 5.27%

Figure 3 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 form 51 in April 2020 to 106 in January 2021.

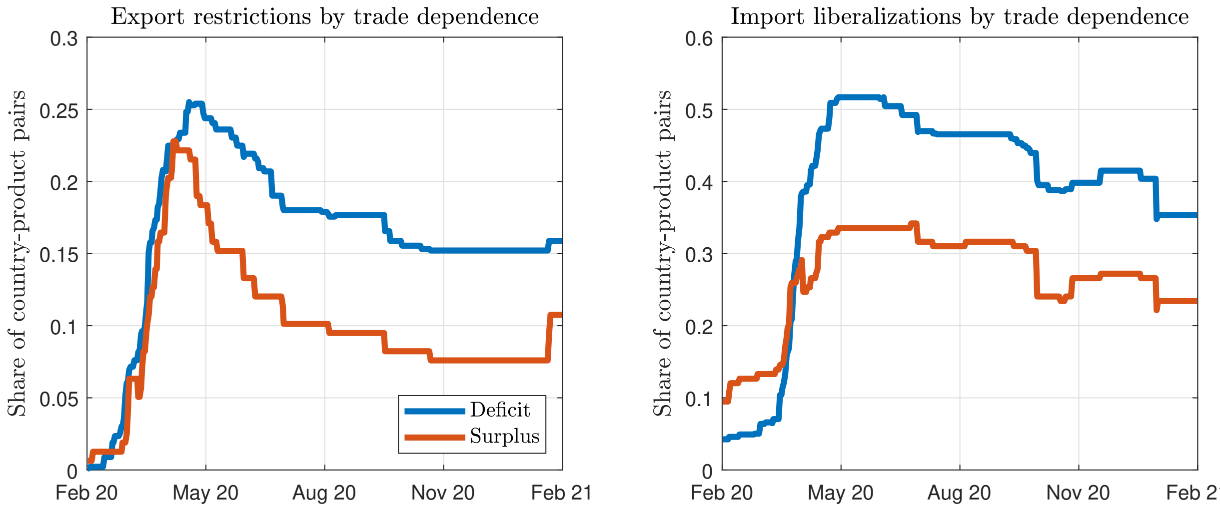
Trade policy To examine how trade policy varies with trade dependence, we measure the latter based on product-level trade imbalances. We classify country-product pairs into two groups based on their trade imbalance in 2019 using data from CEPII: country-pairs with a trade deficit and those with a surplus.[5] For each group, Figure 4 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 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 products were better equipped to scale up production in the face of global shortages.

internal taxation of imports, import quota, import-related non-tariff measure. Industrial policies consists of the introduction or expansion of any of the following policies: financial grant, state aid, state loan, interest payment subsidy, tax or social insurance relief, loan guarantee, production subsidy, localisation incentive, price stabilization, in-kind grant, capital injection and equity.

[5] `http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele.asp`.

Figure 4: 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.

Table 10: Optimal industrial policy and sectoral imbalances

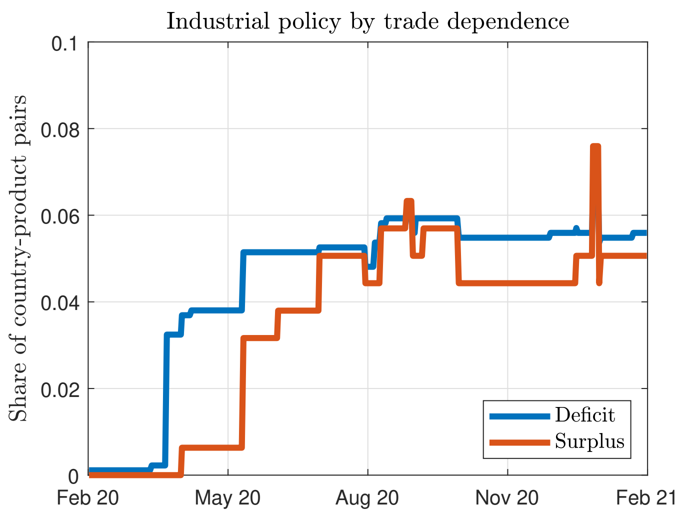
	Total sales subsidy
Trade deficit of essential goods ($\mathrm{NX}_e/\mathrm{GDP}_e = -0.30$)	17.09%
Trade surplus of essential goods ($\mathrm{NX}_e/\mathrm{GDP}_e = 0.30$)	16.17%

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 of the paper as in the baseline, and we recalibrate the parameters from Table 6 of the paper targeting a net exports-to-GDP ratio in essential goods equal to ± 0.30.

We report our findings in Table 9. 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 5 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 10 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 5: 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.

Appendix D: Derivations

5 Planner's problem

5.1 External constraint

- We begin by deriving the external constraint from the competitive equilibrium
- Start by combining the budget constraints of the households:

$$\sum_i [p_t c_{it} + b_{it}] = \sum_i \left[\lambda_i w_t + \pi_{it} + \frac{b_{it+1}}{1+r_t} + \mathcal{T}_{it}\right]$$

- Final good market clearing:

$$p_t y_t + \sum_i b_{it} = \sum_i \left[\lambda_i w_t + \pi_{it} + \frac{b_{it+1}}{1+r_t} + \mathcal{T}_{it}\right]$$

- Plug final good producer objective:

$$p_{nt} n_t + p_{et} e_t + \sum_i b_{it} = \sum_i \left[\lambda_i w_t + \pi_{it} + \frac{b_{it+1}}{1+r_t} + \mathcal{T}_{it}\right]$$

- Replace n and e using market clearing for essential and non-essential:

$$p_{nt} y_{nt} - \sum_i [p_{nt} I_{it} + p_{nt}\phi_k(k_{it+1}, k_{it}) + p_{nt}\phi_\ell(\ell_{it}, \ell_{it-1})] + p_{et} y_{et} + B_t = \sum_i \left[\lambda_i w_t + \pi_{it} + \frac{b_{it+1}}{1+r_t} + \mathcal{T}_{it}\right]$$

- Rearrange:

$$p_{nt} y_{nt} + p_{et} y_{et} + B_t = \frac{B_{t+1}}{1+r_t} + \sum_i [p_{nt} I_{it} + p_{nt}\phi_k(k_{it+1}, k_{it}) + p_{nt}\phi_\ell(\ell_{it}, \ell_{it-1}) + \lambda_i w_t + \pi_{it} + \mathcal{T}_{it}]$$

- Plug profits of sectoral producers:

$$p_{nt} y_{nt} + p_{et} y_{et} + B_t = \frac{B_{t+1}}{1+r_t} + \sum_i [p^d_{it} y^d_{it} + p^x_{it} y^x_{it}]$$

- Simplify using producers of composite goods (CES):

$$\sum_i p^m_{it} y^m_{it} + B_t = \frac{B_{t+1}}{1 + r^* + \Omega_r \left[e^{\left(B_{t+1} - \bar{b}\right)} - 1\right]} + \sum_i p^x_{it} y^x_{it}$$

5.2 Planner's problem: Setup

- Objective function:

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

- Problem:

$$
\begin{aligned}
&\max \mathcal{V}_t = \lambda_n V_{nt} + \lambda_e V_{et}\\
&\text{subject to}\\
&\text{Households}\\
&V_{nt} = \sum_{t=0}^{\infty} \beta^t \frac{(c_{nt}/\lambda_n)^{1-\xi}}{1-\xi}\\
&V_{et} = \sum_{t=0}^{\infty} \beta^t \frac{(c_{et}/\lambda_e)^{1-\xi}}{1-\xi}\\
&\text{Domestic variety e}\\
&k_{et+1} = (1-\delta)k_{et} + I_{et}\\
&y^d_{et} + y^x_{et} = A_e \left(\ell^{\alpha}_{et} k^{1-\alpha}_{et}\right)^{\eta}\\
&\text{Domestic variety n}\\
&k_{nt+1} = (1-\delta)k_{nt} + I_{nt}\\
&y^d_{nt} + y^x_{nt} = A_n \left(\ell^{\alpha}_{nt} k^{1-\alpha}_{nt}\right)^{\eta}\\
&\text{Composite goods}\\
&n_t + \sum_{i\in\{n,e\}} [I_{it} + \phi_k(k_{it+1}, k_{it}) + \phi_\ell(\ell_{it}, \ell_{it-1})] = \left[\omega_n {y^d_{nt}}^{\frac{\sigma-1}{\sigma}} + (1-\omega_n) {y^m_{nt}}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}\\
&e_t = \left[\omega_e {y^d_{et}}^{\frac{\sigma-1}{\sigma}} + (1-\omega_e) {y^m_{et}}^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}\\
&\text{Final goods}\\
&c_{et} + c_{nt} = \left[(1-\gamma) n_t^{\frac{\rho-1}{\rho}} + \gamma \left(\frac{e_t}{\overline{e}_t}\right)^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}\\
&\text{Labor}\\
&\lambda_n + \lambda_e = \ell_{nt} + \ell_{et}\\
&\text{External constraint}\\
&p^m_{nt} y^m_{nt} + p^m_{et} y^m_{et} + B_t = \frac{B_{t+1}}{1 + r^* + \Omega_r \left[e^{\left(B_{t+1} - \overline{b}\right)} - 1\right]} + p^x_{nt} y^x_{nt} + p^x_{et} y^x_{et}
\end{aligned}
$$

5.3 Planner's problem: Solution

- Lagrangian:

$$
\begin{aligned}
\mathcal{L} = & \lambda_n \sum_{t=0}^{\infty} \beta^t \frac{(c_{nt}/\lambda_n)^{1-\xi}}{1-\xi} + \lambda_e \sum_{t=0}^{\infty} \beta^t \frac{(c_{et}/\lambda_e)^{1-\xi}}{1-\xi} \\
& + \sum_{t=0}^{\infty} \mu_{et} \left[A_e \left(\ell_{et}^{\alpha} k_{et}^{1-\alpha} \right)^{\eta} - y_{et}^{d} - y_{et}^{x} \right] \\
& + \sum_{t=0}^{\infty} \mu_{nt} \left[A_n \left(\ell_{nt}^{\alpha} k_{nt}^{1-\alpha} \right)^{\eta} - y_{nt}^{d} - y_{nt}^{x} \right] \\
& + \sum_{t=0}^{\infty} \Phi_{nt} \left\{ \left[\omega_n {y_{nt}^{d}}^{\frac{\sigma-1}{\sigma}} + (1-\omega_n) {y_{nt}^{m}}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} - n_t - \sum_{i \in \{n,e\}} \left[k_{it+1} - (1-\delta) k_{it} + \phi_k(k_{it+1}, k_{it}) + \phi_\ell(\ell_{it}, \ell_{it-1}) \right] \right\} \\
& + \sum_{t=0}^{\infty} \Phi_{et} \left\{ \left[\omega_e {y_{et}^{d}}^{\frac{\sigma-1}{\sigma}} + (1-\omega_e) {y_{et}^{m}}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} - e_t \right\} \\
& + \sum_{t=0}^{\infty} \Phi_{ft} \left\{ \left[(1-\gamma) n_t^{\frac{\rho-1}{\rho}} + \gamma \left(\frac{e_t}{\bar{e}_t} \right)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}} - c_{et} - c_{nt} \right\} \\
& + \sum_{t=0}^{\infty} \Phi_{Lt} \left\{ \ell_{nt} + \ell_{et} - \lambda_n - \lambda_e \right\} \\
& + \sum_{t=0}^{\infty} \theta_t \left\{ p_{nt}^{x} y_{nt}^{x} + p_{et}^{x} y_{et}^{x} + \frac{B_{t+1}}{1 + r^* + \Omega_r \left[e^{\left(B_{t+1} - \bar{b}\right)} - 1 \right]} - B_t - p_{nt}^{m} y_{nt}^{m} - p_{et}^{m} y_{et}^{m} \right\}
\end{aligned}
$$

- FOC B_{t+1}:

$$
\frac{\theta_{t+1}}{\theta_t} = \left[\frac{1}{1 + r^* + \Omega_r \left[e^{\left(B_{t+1} - \bar{b}\right)} - 1 \right]} - \frac{B_{t+1} \Omega_r e^{\left(B_{t+1} - \bar{b}\right)}}{\left(1 + r^* + \Omega_r \left[e^{\left(B_{t+1} - \bar{b}\right)} - 1 \right] \right)^2} \right]
$$

- FOC k_{it+1}:

$$
\mu_{it+1} (1-\alpha) \eta A_i \left(\ell_{it+1}^{\alpha} k_{it+1}^{1-\alpha} \right)^{\eta} / k_{it+1} + \Phi_{nt+1} (1-\delta) - \Phi_{nt+1} \frac{\partial \phi_k(k_{it+2}, k_{it+1})}{\partial k_{it+1}} = \Phi_{nt} \left[1 + \frac{\partial \phi_k(k_{it+1}, k_{it})}{\partial k_{it+1}} \right]
$$

- FOC ℓ_{it}:

$$
\mu_{it} \left[\alpha \eta A_i \left(\ell_{it}^{\alpha} k_{it}^{1-\alpha} \right)^{\eta} / \ell_{it} \right] - \Phi_{nt} \frac{\partial \phi_\ell(\ell_{it}, \ell_{it-1})}{\partial \ell_{it}} - \Phi_{nt+1} \frac{\partial \phi_\ell(\ell_{it+1}, \ell_{it})}{\partial \ell_{it}} + \Phi_{Lt} = 0
$$

- FOC y_{it}^{x}:

$$
-\mu_{it} + \theta_t p_{it}^{x} = 0
$$

- FOC y_{it}^{m}:

$$
\frac{\theta_t p_{it}^{m}}{\left[\omega_i {y_{it}^{d}}^{\frac{\sigma-1}{\sigma}} + (1-\omega_i) {y_{it}^{m}}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}} (1-\omega_i) {y_{it}^{m}}^{\frac{-1}{\sigma}}} = \Phi_{it}
$$

- FOC y^d_{it}:

$$\frac{\mu_{it}}{\left[\omega_i y^{d\frac{\sigma-1}{\sigma}}_{it} + (1-\omega_i) y^{m\frac{\sigma-1}{\sigma}}_{it}\right]^{\frac{\sigma}{\sigma-1}-1} \omega_i y^{d\frac{-1}{\sigma}}_{it}} = \Phi_{it}$$

- FOC n_t:

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

- FOC e_t:

$$\Phi_{ft} = \Phi_{et}\left[c_{et}+c_{nt}\right]^{\frac{-1}{\rho}} \frac{1}{\gamma}\left(\frac{1}{\bar{e}_t}\right)^{\frac{1-\rho}{\rho}} (e_t)^{\frac{1}{\rho}}$$

- FOC c_{it}:

$$\lambda_i \beta^t \lambda_i^{\xi-1} c_{it}^{-\xi} = \Phi_{ft}$$

6 Competitive equilibrium

Let $R_t = 1 + r_t$.

6.1 Households

- Lagrangian:

$$\mathcal{L}_{i0} = \sum_{t=0}^{\infty} \beta^t \frac{(c_{it}/\lambda_i)^{1-\xi}}{1-\xi} + \sum_{t=0}^{\infty} \beta^t \kappa_{it}\left\{\lambda_i w_t + \pi_{it} + \frac{b_{it+1}}{1+r_t} + \mathcal{T}_{it} - p_t c_{it} - b_{it}\right\}$$

- FOC c_{it}: $\lambda_i^{1-\xi} c_{it}^{-\xi} = \kappa_{it} p_t$
- FOC b_{it+1}: $\beta \frac{c_{it}^{\xi}}{c_{it+1}^{\xi}} = \frac{p_{t+1}}{p_t} \frac{R_t - b_{it+1}\Omega_r\left[e^{\left(b_{nt+1}+b_{et+1}-\bar{b}\right)}\right]}{R_t^2}$

6.2 Producers of final goods

- FOC e_t: $p_t y_t^{\frac{1}{\rho}} \gamma\left(\frac{1}{\bar{e}_t}\right)^{\frac{\rho-1}{\rho}} e_t^{\frac{-1}{\rho}} = p_{et}$
- FOC n_t: $p_t\left[(1-\gamma)n_t^{\frac{\rho-1}{\rho}} + \gamma\left(\frac{e_t}{\bar{e}_t}\right)^{\frac{\rho-1}{\rho}}\right]^{\frac{1}{\rho-1}} (1-\gamma)n_t^{\frac{-1}{\rho}} = p_{nt}$

6.3 Producer of composite good $j \in \{n, e\}$

- FOC q^d_{jt}: $p_{jt} = \frac{1}{\omega_j} p^d_{jt} y_{jt}^{\frac{-1}{\sigma}} q^{d\frac{1}{\sigma}}_{jt}$
- FOC q^m_{jt}: $p_{jt} = \frac{1}{(1-\omega_j)}(1+\tau^m_{jt})\tau_j p^m_{jt} y_{jt}^{\frac{-1}{\sigma}} q^{m\frac{1}{\sigma}}_{jt}$

6.4 Producer of domestic variety $j \in \{n, e\}$

- Lagrangian:

$$\mathcal{L} = \sum_{t=0}^{\infty} m_{jt} \Bigg[(1+\tau^y_{jt}) \left(\omega_j y_{jt}\right)^{\frac{1}{\sigma}} p_{jt} \left(y^d_{jt}\right)^{\frac{\sigma-1}{\sigma}} + (1+\tau^y_{jt} - \tau^x_{jt}) p^x_{jt} \left[A_j \left(\ell^{\alpha}_{jt} k^{1-\alpha}_{jt}\right)^{\eta} - y^d_{jt} \right]$$

$$- w_t \ell_{jt} - p_{nt} \left(k_{jt+1} - (1-\delta) k_{jt}\right) - p_{nt} \phi_k(k_{jt+1}, k_{jt}) - p_{nt} \phi_\ell(\ell_{jt}, \ell_{jt-1}) \Bigg]$$

$$+ \Upsilon_{jt} \left[A_j \left(\ell^{\alpha}_{jt} k^{1-\alpha}_{jt}\right)^{\eta} - y^d_{jt} \right]$$

- FOC ℓ_{jt}:

$$m_{jt} \left[(1+\tau^y_{jt} - \tau^x_{jt}) p^x_{jt} A_j \eta \left(\ell^{\alpha}_{jt} k^{1-\alpha}_{jt}\right)^{\eta-1} \alpha \ell^{\alpha-1}_{jt} k^{1-\alpha}_{jt} - w_t - p_{nt} \frac{\partial \phi_\ell(\ell_{jt}, \ell_{jt-1})}{\partial \ell_{jt}} \right] - m_{jt+1} \left[p_{nt+1} \frac{\partial \phi_\ell(\ell_{jt+1}, \ell_{jt})}{\partial \ell_{jt}} \right]$$
$$+ \Upsilon_{jt} A_j \eta \left(\ell^{\alpha}_{jt} k^{1-\alpha}_{jt}\right)^{\eta-1} \alpha \ell^{\alpha-1}_{jt} k^{1-\alpha}_{jt} = 0$$

- FOC k_{jt+1}:

$$m_{jt} \left[-p_{nt} - p_{nt} \frac{\partial \phi_k(k_{jt+1}, k_{jt})}{\partial k_{jt+1}} \right] +$$
$$m_{jt+1} \left[(1+\tau^y_{jt+1} - \tau^x_{jt+1}) p^x_{jt+1} A_j \eta \left(\ell^{\alpha}_{jt+1} k^{1-\alpha}_{jt+1}\right)^{\eta-1} (1-\alpha) \ell^{\alpha}_{jt} k^{-\alpha}_{jt+1} + p_{nt+1}(1-\delta) - p_{nt+1} \frac{\partial \phi_k(k_{jt+2}, k_{jt+1})}{\partial k_{jt+1}} \right] = 0$$

- FOC y^d_{jt}:

$$m_{jt} \left[(1+\tau^y_{jt}) \left(\omega_j y_{jt}\right)^{\frac{1}{\sigma}} p_{jt} \frac{\sigma - 1}{\sigma} \left(y^d_{jt}\right)^{\frac{-1}{\sigma}} - (1+\tau^y_{jt} - \tau^x_{jt}) p^x_{jt} \right] - \Upsilon_{jt} = 0$$

- Complementary slackness:

$$\Upsilon_{jt} \left[A_j \left(\ell^{\alpha}_{jt} k^{1-\alpha}_{jt}\right)^{\eta} - y^d_{jt} \right] = 0$$

6.5 Government budget constraint

- Budget constraint:

$$\mathcal{T}_{nt} + \mathcal{T}_{et} = \sum_{j \in \{n,e\}} \left\{ \tau^m_{jt} \tau_j p^m_{jt} q^m_{jt} + \tau^x_{jt} p^x_{jt} y^x_{jt} - \tau^y_{jt} \left[p^d_{jt} y^d_{jt} + p^x_{jt} y^x_{jt} \right] \right\}$$

6.6 Market clearing conditions

- Labor: $\lambda_n + \lambda_e = \ell_{nt} + \ell_{et}$
- Domestic varieties of good $i \in \{n, e\}$: $q^d_{it} = y^d_{it}$
- Composite essential goods: $e_t = y_{et}$
- Composite non-essential goods: $n_t + \sum_{j \in \{n,e\}} \left[I_{jt} + \phi_k(k_{jt+1}, k_{jt}) + \phi_\ell(\ell_{jt}, \ell_{jt-1}) \right] = y_{nt}$
- Final goods: $\sum_i c_{it} = y_t$

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