GRAPE Working Paper #47

Strategic inefficiencies and federal redistribution during uncoordinated response to pandemic waves

Jacek Rothert

FAME | GRAPE, 2020

Foundation of Admirers and Mavens of Economics
Group for Research in Applied Economics

Strategic inefficiencies and federal redistribution during uncoordinated response to pandemic waves

Jacek Rothert
United States Naval Academy,
and FAME|GRAPE

Abstract
Optimal policy during an epidemic includes depressing economic activity to slow down the outbreak. Sometimes, these decisions are left to local authorities (e.g. states). This creates an externality, as the outbreak does not respect states' boundaries. The externality directly exacerbates the outbreak. Indirectly, it creates a free-rider problem, because local policymakers pass the cost of fighting the outbreak on to other states. A standard system of distortionary taxes and lump-sum transfers can implement the optimal allocation, with higher tax rates required if states behave strategically. A strategic system of taxes and transfers, rewarding states which depress their economies more than average, improves the outcomes by creating a race-to-the-bottom type of response. In a symmetric equilibrium, the optimal tax rate is lower if states behave strategically.

Keywords:
Covid-19; strategic Pigouvian taxation; pandemic waves; fiscal federalism; free-riding; race-to-the-bottom

JEL Classification
D62, H77, H21, H23, I19

Corresponding author
Jacek Rothert, jacek.rothert@gmail.com

Acknowledgements
I thank Alex McQuoid, Jacob Short, Katherine Smith, and colleagues at the U.S. Naval Academy, as well as two anonymous referees, for insightful discussions and comments on the preliminary versions of this work. I gratefully acknowledge the support of NCN grant #2019/35/B/HS4/0076. The views expressed here are those of the author and do not represent the views of the United States Naval Academy, the Department of Defense, or the Federal Government. All errors are mine.

Published by: FAME | GRAPE
ISSN: 2544-2473

Foundation of Admirers and Mavens of Economics
ull. Mazowiecka 11/14
00-052 Warszaw
Poland

W | grape.org.pl
E | grape@grape.org.pl
TT | GRAPE_ORG
FB | GRAPE.ORG
PH | +48 799 012 202

1 Introduction

In this paper, I analyze the nature and sources of inefficiencies that arise during an uncoordinated response to a disease outbreak. As the Covid-19 epidemic spreads across the world, countries impose various types of restrictions on economic activity in an effort to slow down the outbreak. In the United States, restrictions are largely left to individual states to determine and implement. Since the virus does not recognize state and country borders (Eckardt et al., 2020; Rothert et al., 2020), and complete border closure between states is practically impossible, this creates a clear externality: one state may implement a very restrictive policy that limits contact between people and creates a recession in the state, only to see the virus spread locally, because neighboring states did not do the same. This poses a number of important questions. First, how do the inter-regional epidemiological spillovers affect the outcomes during an uncoordinated response to a pandemic? Second, how do those spillovers combined with the strategic interaction between the regions affect the decisions made by policymakers? Third, what tools (complex and simple) can be used to at least partially correct the inefficiencies that arise in the non-cooperative equilibrium? I address these questions using an analytical framework with two regions where the new infections depend on (1) the severity of local transmission and the level of economic activity within a region, and (2) on the lagged infections in the neighboring region. Not surprisingly, when regional policymakers act in an uncoordinated manner, each will implement restrictions and policies that are too lenient. There are two inefficiencies that lead to such an outcome. First, since each policymaker is primarily concerned with his or her own region, he or she does not take into account the marginal benefit that the *other* region would enjoy from the implementation of stricter policies and restrictions within his or her region. The second inefficiency is more subtle and arises from the strategic interaction between the regions. When policymakers understand the existence of inter-regional spillovers and take into account other policymakers' decisions, they have an incentive to pass the economic cost of fighting the pandemic on to the other region, moving the non-cooperative equilibrium farther away from the optimal allocation.

I then consider two types of fiscal tools that can be used at the federal level to either implement the optimal allocation, or at least move the non-cooperative allocation closer to it. First, I characterize the optimal Pigouvian system of time-varying optimal taxes and transfers that fully correct all of the externalities present in this environment. In the long-run, the optimal tax rates are higher when the policymakers act strategically.

Second, I analyze the effects of a partial inter-state redistribution, where a federal tax τ is imposed on the difference between the two regions' economic activities, rather than on the economic activity itself. Such strategic Pigouvian tax moves the non-cooperative allocation closer to the optimum. In a special case of identical regions, the optimal allocation in the long-run can be implemented with an appropriately chosen strategic tax rate. Moreover, since the two regions are identical, *in equilibrium no region receives a transfer*: the very presence of the policy gives each policymaker an incentive to depress the economy more then they otherwise would, by generating a race-to-the-bottom type of response which implements the optimal allocation. The logic is very similar to that of the tax competition literature (Wilson, 1986): states compete for transfers from the federal government by depressing their economies. Interestingly, the tax rate that implements optimal allocation is smaller when the two regional policymakers internalize each other's strategies.

While the paper considers a simple theoretical framework, it is motivated by an increasingly abundant empirical literature that analyzes spatial diffusion of Covid-19 in the United States and other parts of the world. Eckardt et al. (2020) provided evidence of potential epidemiological spillovers between countries in the European Union. They showed that border closures in the Schengen Zone significantly slowed down the spread of the virus within the EU. Unlike the members of the EU, the states in the United States cannot close their borders, which means that such spillovers between states are harder to contain. Rothert et al. (2020) showed that new Covid-19 cases diffused across county lines within the United States, and that the diffusion across counties was affected by the closure policies of adjacent states. They also showed that lax policies in the most lenient states would translate into millions of additional infections in other parts of the country in the long-run. Kuchler et al. (2020) showed that the increase in new Covid-19 cases in various counties was linked to the degree of social connections between a county and the outbreak "hotspots". Brinkman and Mangum (2020) showed that a reduction in travel activity mitigated the initial spread in the United States. Finally, as a case study of one "superspreading" event, Dave et al. (2020) showed that the organization of the Sturgis Motorcycle Rally contributed to increased outbreaks in other parts of the country.

The economics of Covid-19 is a rapidly expanding field. However, little work thus far has been done to explore the issues associated with inter-state and inter-regional coordination of mitigation policies. In one of the earliest studies Beck and Wagner (2020) focused on the timing of optimal coordination, arguing that in the long-run, governments impose restrictions which are too lenient. Their study focuses on international cooperation, hence it is silent about the possible fiscal tools that could be used in a federation of states. In a closely related paper (Rothert, 2020), I used a simplified, static version of the model presented here and analyzed problems that would arise when some states could not easily redistribute resources between households and when different households were impacted differently by imposed restrictions. This paper abstracts from the within-state redistribution, but extends the analysis to a dynamic framework which allows for a more nuanced analysis of strategic interactions between the regions.

The main focus here is on the policy response. This relates the paper to the early studies that focused on the variation in policy response and compliance with restrictions across regions. Allcott et al. (2020) argued that political preferences of a region mattered for that region's response, while Painter and Qiu (2020) showed that compliance with lockdown policies was affected by peoples' political beliefs. Rothert et al. (2020) also documented a substantial heterogeneity across U.S. states in the scope of lockdown measures imposed. The main contribution of this paper is the framework to analyze the problem of uncoordinated response to the outbreak across different regions/states.

Finally, this paper is closely related to the rich literature on the coordination and competition between regions. That problem has been extensively studied in the context of the tax competition between states and countries in a financially integrated area (Wilson, 1986; Janeba and Wilson, 2011; Chirinko and Wilson, 2017). The general idea is that states undercut each other by lowering capital income tax, in order to attract foreign companies and collect the capital income tax revenues. The game between the states takes the form of a Prisoner's Dilemma, so in the non-cooperative equilibrium all states have lower tax rates and lower tax revenues than they would have had they coordinated. The logic of this paper is similar: states are willing to depress their economies more if that would lead to a higher federal transfer of resources.

2 Dynamic model of inter-regional pandemic waves

Time is discrete, with an infinite horizon. A country consists of two regions: North (N) and South (S). At some period t, the world is hit with a pandemic. The pandemic lasts until either the virus disappears or an effective vaccine is developed. The probability that the pandemic will end due to one of these events is assumed constant, and equal to $1-\delta$ (so δ is the probability the outbreak continues next period).

Post-pandemic world In normal times the period utility of a stand-in household is given by:

$$u(c) - v(\ell),$$

with $u', v', v'' > 0$ and $u'' < 0$. Production function is linear in labor, so the resource constraint in each region is $c = \ell$. The life-time post-pandemic utility is then given by:

$$V^R = \max_{\ell} u(\ell) - v(\ell) + \beta V^R,$$

where β is the discount factor. That yields $V^R \equiv \frac{u(\ell^*)-v(\ell^*)}{1-\beta}$, where ℓ^* solves $u'(\ell^*) = v'(\ell^*)$.

The world during the pandemic During the pandemic, the period utility of a stand-in household in region $i = N, S$ is given by:

$$u(c_i) - v(\ell_i) - h(p_i) \tag{2.1}$$

where p denotes the number of people infected in that period. That number is assumed to depend on the severity of local transmission as well as on the number of people infected in the other region in the previous period:

$$p_i = \psi_i \cdot g(\ell_i) + \kappa(Lp_{-i}) \tag{2.2}$$

where L is the lag operator, $\psi_i \in \{\psi^H, \psi^L\}$ is the severity of local transmission in region i, $\kappa(\cdot)$ captures the impact of inter-regional spillovers, and $g(\cdot)$ captures the impact of the local economic activity on the number of new local infections. The severity of local transmission ψ varies across regions and over time. In even periods it is high in the North and low in the South ($\psi_N = \psi^H \geq \psi^L = \psi_S > 0$). In odd periods it is high in the South and low in the North. The end of the pandemic means that $\psi_N = \psi_S = 0$. Functions $\kappa(\cdot)$ and $g(\cdot)$ are both assumed to be strictly increasing and weakly convex ($g', \kappa' > 0$, $g'', \kappa'' \geq 0$). Additionally, I assume that $0 < \kappa' < 1$ and that the ratio $\frac{v'(\ell)}{g'(\ell)}$ is non-decreasing in ℓ.

Fiscal federalism The two regions form a federation. Each region is managed independently by its own governor who can impose temporary restrictions on the number of hours worked. Each region can be required to pay taxes to the federal government and is also eligible to receive federal transfers.

2.1 Optimal allocation

The state of the world is a tuple (j, Lp_N, Lp_S), where $j \in \{N, S\}$ denotes the region in which the degree of local transmission is high, while Lp_N and Lp_S denote the number of people infected in each region in the previous period. The optimal allocation solves the following planner's problem:

$$V(j, Lp_N, Lp_S) = \max_{c_i, \ell_i, p_i} \sum_{i \in \{S,N\}} [u(c_i) - v(\ell_i) - h(p_i)] + \beta\left[\delta V(-j, p_N, p_S) + (1-\delta) V^R\right]$$

subject to:

$$\ell_N + \ell_S \geq c_N + c_S$$

$$p_i \geq \psi_i(j)g(\ell_i) + \kappa(Lp_{-i}), \qquad i = N, S$$

where

$$\psi_i(j) := \begin{cases} \psi^H, & \text{if } i = j \\ \psi^L, & \text{if } i \neq j \end{cases} \tag{2.3}$$

Definition 2.1 (Optimal policy)**.** The optimal policy is a function $\pi^* := [\pi_N^*, \pi_S^*] : \{N, S\} \times \mathbb{R}_+^2 \to \mathbb{R}_+^2$ such that $(p_N^*, p_S^*) = \pi^*(j, Lp_N, Lp_S)$ solves the above planner's problem, for all $(j, Lp_N, Lp_S) \in \{N, S\} \times \mathbb{R}_+^2$.

In the long-run, in the event that no vaccine is invented and the virus does not disappear, the optimal allocation becomes stationary. The formal definition is as follows.

Definition 2.2 (Stationary optimal allocation)**.** Optimal stationary allocation is a tuple $(\ell_H^*, \ell_L^*, p_H^*, p_L^*)$ such that:

- $p_H^* = \pi_N^*\left(N, p_L^*, p_H^*\right) = \pi_S^*\left(S, p_H^*, p_L^*\right)$ and $p_L^* = \pi_N^*\left(S, p_H^*, p_L^*\right) = \pi_S^*\left(N, p_L^*, p_H^*\right)$
- $p_s^* = \psi^s g\left(\ell_s^*\right) + \kappa\left(p_s^*\right), \qquad s = H, L$

2.2 Non-cooperative allocation

A non-cooperative allocation is an outcome of a strategic interaction between the two governors.

Players, actions, and payoffs There are two players: governors of the North and of the South. The action of each governor i is $p_i \in \mathbb{R}_+$: the number of people infected in a given period (notice that there is a one-to-one mapping between current period p and ℓ given by (2.2)). The per-period payoff is given by (2.1).

Markov strategies I will restrict my attention to Markov strategies: governor i conditions his or her action p_i on the current state of the world, given by (j, Lp_N, Lp_S), where j identifies the region with high degree of local transmission. Hence, the strategy space is the set of functions that map $\{N, S\} \times \mathbb{R}_+^2$ into $\mathbb{R}_+$. The strategy of governor of i will be denoted with π_i and, given the specification of $\kappa(\cdot)$, I will only consider strategies such that $\frac{\partial \pi_i}{\partial Lp_i} = 0$ — past infections in region i do not impact current policy in region i.

Dynamic program Without loss of generality, let W denote the value function for the governor of the North. The dynamic programming problem of the governor can be written as:

$$W(j, Lp_N, Lp_S) = \max_{c_N, \ell_N, p_N} u(c_N) - v(\ell_N) - h(p_N) + \beta\left[\delta W(-j, p_N, p_S) + (1-\delta)V^R\right] \tag{2.4}$$

subject to:

$$c_N \leq \ell_N \tag{2.5}$$

$$p_N \geq \psi_N(j) \cdot g(\ell_N) + \kappa(Lp_S) \tag{2.6}$$

$$p_S \geq \pi_S(j, Lp_N) \tag{2.7}$$

where $\psi_N(j)$ is given by (2.3). The problem in the South is analogous.

Constraint (2.7) can be written more explicitly as:

$$p_S \geq \pi_S(j, Lp_N) \equiv \psi_S(j) \cdot g(\ell_S(j, Lp_N)) + \kappa(Lp_N),$$

which emphasizes that there are two ways in which $p_{N,t}$ may impact $p_{S,t+1}$: the direct way via the externality $\kappa(p_{N,t})$, and the indirect way via the impact on the lock-down policy in the South $\ell_S(-j, p_{N,t})$. The direct way will always be present. The indirect way will depend on the nature of strategic interaction between the two regions.

Stackelberg and Cournot equilibria I will consider two types of strategic interaction, in both cases focusing on Markovian strategies and equilibria. In the first one, the governor of region i will take as given the whole *policy function* $\hat{\pi}_{-i}$ of the other governor. Hence, the governor internalizes the fact that his or her own actions in period t will impact the behavior of the other governor in period $t+1$, in particular the choice of $\ell_{-i,t+1}$. I will refer to that equilibrium as the Stackelberg Markov Equilibrium.

In the second one, the governor of region i takes as given the forecast of restrictions imposed in the other region. A forecast of restrictions $\tilde{\ell}_{-i} \equiv \left(\tilde{\ell}_{-i,t}\right)_{t=1}^{\infty}$ is defined as a sequence of functions $\tilde{\ell}_{-i,t}$: $\left\{\left\{0, \psi^L, \psi^H\right\} \times \left\{0, \psi^L, \psi^H\right\}\right\}^t \rightarrow \mathbb{R}_+$. Notice that any forecast is conditional on the timing of when the pandemic ends (the first time when $\psi_N = \psi_S = 0$). An equilibrium in which the governor i takes $\tilde{\ell}_{-i}$ as given assumes the governor does not internalize the fact that his or her action in period t will impact the behavior of the other governor in period $t+1$, in particular their choice of $\ell_{-i,t+1}$. Instead, it takes as given the *forecast* of restrictions in the other region. In equilibrium, that forecast will be required to be consistent with the actual behavior. I will refer to that equilibrium as the Cournot Markov Equilibrium.

Mechanically, the difference between the two types of strategic interactions can be described in terms of the derivative of π_S w.r.t. Lp_N:

$$\pi_S'(Lp_N) = \psi_S \cdot g'(\ell_S) \cdot \ell_S'(Lp_N) + \kappa'(Lp_N) \qquad \text{Stackelberg}$$

$$\pi_S'(Lp_N) = \kappa'(Lp_N) \qquad \text{Cournot}$$

The formal definitions of the two equilibria are as follows.

Definition 2.3 (Stackelberg Markov Equilibrium)**.** A Stackelberg Markov Equilibrium is a tuple $(\hat{\pi}_i)_{i=N,S}$, such that for for each i, $\hat{\pi}_i$ is the optimal policy function for the dynamic program (2.4), given $\hat{\pi}_{-i}$.

Definition 2.4 (Cournot Markov Equilibrium)**.** A Cournot Markov Equilibrium is a tuple $(\hat{\pi}_i)_{i=N,S}$, such that for each i, $\hat{\pi}_i$ is the optimal policy function for the dynamic program (2.4) given the forecast $\tilde{\ell}_{-i}$, and such that for any realization of $(\psi_{N,t}, \psi_{S,t})_{t=1}^{\infty}$ the sequence of labor allocations implied by $\hat{\pi}_i$ is consistent with the forecast $\tilde{\ell}_i$ made by governor $-i$, for $i = N, S$.

In the long-run, assuming no vaccine is developed and the virus does not disappear, the non-cooperative allocation becomes stationary.

Definition 2.5 (Symmetric stationary equilibrium)**.** A symmetric stationary equilibrium is a tuple $\left(\hat{\ell}_s, \hat{p}_s\right)_{s=H,L}$, such that:

- $\hat{p}_H = \hat{\pi}_i(i, \hat{p}_H) = \psi^H g(\hat{\ell}_H) + \kappa(\hat{p}_H)$, $i = N, S$
- $\hat{p}_L = \hat{\pi}_i(-i, \hat{p}_L) = \psi^L g(\hat{\ell}_L) + \kappa(\hat{p}_L)$, $i = N, S$

3 Optimal vs. non-cooperative outcomes

3.1 Sources of inefficiencies

To better understand the sources of inefficiencies that arise in the non-cooperative Markov equilibrium, consider the equations that characterize the optimal and the non-cooperative allocation in the North (the equations for the South are analogous). Let $\lambda_N(j)$ be the Lagrange multiplier on the epidemiological constraint (2.6) in the North, when region j experiences high degree of local transmission. In the optimal (asterisks) and the non-cooperative (hats) allocations $\lambda_N(j)$ is given by:

$$\lambda_N^*(j) = \frac{u'\left(\frac{\ell_N^* + \ell_S^*}{2}\right) - v'\left(\ell_N^*\right)}{\psi_N(j) g'\left(\ell_N^*\right)} \qquad \text{and} \qquad \hat{\lambda}_N(j) = \frac{u'\left(\hat{\ell}_N\right) - v'\left(\hat{\ell}_N\right)}{\psi_N(j) g'\left(\hat{\ell}_N\right)} \tag{3.1}$$

We then get the following inter-temporal conditions in the optimal vs. in the non-cooperative allocation (see Appendix A.1 for derivation):

$$\text{optimal:} \qquad \lambda^*_{N,t}(j) = h'(p^*_{N,t}) + \beta\delta \cdot \kappa'(p^*_{N,t}) \cdot \left[h'(p^*_{S,t+1}) + \beta\delta\kappa'(p^*_{S,t+1})\lambda^*_{N,t+2}(j)\right] \tag{3.2}$$

$$\text{non-cooperative:} \qquad \hat{\lambda}_{N,t}(j) = h'(\hat{p}_{N,t}) + \beta\delta \cdot \pi'_S(\hat{p}_{N,t}) \cdot \left[\quad 0 \quad + \beta\delta\kappa'(\hat{p}_{S,t+1})\hat{\lambda}_{N,t+2}(j)\right] \tag{3.3}$$

where $\pi'_S(p) := \frac{\partial \pi_S(-j,p)}{\partial p}$.

The first-order conditions (3.1) - (3.3) indicate three sources of inefficiencies in the non-cooperative allocation. The first source is intra-temporal. The two conditions in (3.1) show that in the optimal allocation the social planner would pool resources by equating consumption across the two regions. That risk sharing is absent in the non-cooperative allocation in the model. The other two sources are inter-temporal and arise from the impact of $p_{N,t}$ on $p_{S,t+1}$.

The first inter-temporal inefficiency is very intuitive: the policymaker in the North does not care about the cost that South will have to pay, so the term $h'(p^*_{S,t+1})$, which captures the marginal cost of $p_{S,t+1}$, disappears in (3.3). The second one is more nuanced and depends on the degree of strategic interaction between the two policymakers. In the optimal allocation, the impact of $p_{N,t}$ on $p_{S,t+1}$ is captured by the term $\kappa'(p^*_{N,t})$. In the non-cooperative allocation it is captured by $\pi'_S(\hat{p}_{N,t})$. In the Cournot equilibrium, the policymaker in the North does not internalize the impact of $p_{N,t}$ and $\kappa(p_{N,t})$ on the policy in the South, so $\pi'_S(\hat{p}_{N,t}) = \kappa'(p_{N,t})$. In the Stackelberg equilibrium they do, so $\pi'_S(p_{N,t}) < \kappa'(p_{N,t})$. Intuitively, the policymaker in the North lets the policymaker in the South pay part of the economic cost of battling the pandemic.

3.2 Long-run outcomes

In the long-run, for any endogenous variable $x \in \{c, \ell, p\}$, we will have $x_{N,t} = x_{S,t+1}$, for any t. Re-arranging (3.2) and (3.3) we obtain the following conditions that the optimal and non-cooperative stationary allocations must satisfy in the long-run:

$$\frac{u'\left(\frac{\ell^*_H + \ell^*_L}{2}\right) - v'\left(\ell^*_H\right)}{\psi^H g'\left(\ell^*_H\right)} = \frac{h'(p^*_H)}{1 - (\beta\delta)^2 \kappa'(p^*_H) \cdot \kappa'(p^*_H)} + \frac{h'(p^*_H) \cdot \beta\delta \cdot \kappa'(p^*_H)}{1 - (\beta\delta)^2 \kappa'(p^*_H)^2} \qquad \text{optimal}$$

$$\frac{u'\left(\hat{\ell}_H\right) - v'\left(\hat{\ell}_H\right)}{\psi^H g'\left(\hat{\ell}_H\right)} = \frac{h'(\hat{p}_H)}{1 - (\beta\delta)^2 \kappa'(\hat{p}_H) \cdot \pi'_L(\hat{p}_H)} \qquad \text{non-cooperative}$$

with similar conditions holding for the region with $\psi = \psi^L$. The differences between the long-run outcomes in the two allocations, as well as between the Stackelberg and Cournot non-cooperative allocations, are summarized in Proposition 3.1.

Proposition 3.1 (Symmetric stationary allocations)**.** *Let z^* be the optimal stationary allocation, let $\hat{z}\left(\mathcal{S}\right)$ and $\hat{z}\left(\mathcal{C}\right)$ be the stationary allocations in the Stackelberg and Cournot equilibrium, respectively, with a similar notation for individual elements. Then:*

1. $\hat{c}_H(\mathrm{m}) > c^*$, $\hat{\ell}_H(\mathrm{m}) > \ell^*_H$, *and* $\hat{p}_H(\mathrm{m}) > p^*_H$, $\quad \mathrm{m} = \mathcal{S}, \mathcal{C}$
2. *if* $\kappa' = 0$ *then* $\ell^*_L(\mathrm{m}) > \hat{\ell}_L$, $\quad \mathrm{m} = \mathcal{S}, \mathcal{C}$
3. $\hat{\ell}_s(\mathcal{S}) > \hat{\ell}_s(\mathcal{C})$, $\quad s = H, L$

Proof. See Appendix A.2. □

In words, relative to the non-cooperative allocation, the social planner will choose a lower level of economic activity in the region with a high level of local transmission. In general, we cannot establish the same result for the region with a low degree of local transmission. The reason is that the social planner wants to redistribute resources between regions. Since the planner unambiguously wants to lower employment in the region with high local transmission ($\ell^*_H < \hat{\ell}_H$), she is tempted to increase ℓ_L in order to facilitate the redistribution. In general, whether ℓ^*_L is higher or lower than $\hat{\ell}_L$ depends on (1) the curvature of the utility function u (the greater the curvature, the stronger the redistributive motive, and the more likely it is that $\ell^*_L > \hat{\ell}_L$), and (2) on the degree of the epidemiological spillovers between regions, measured by κ' (the greater the spillover, the more likely it is that $\ell^*_L < \hat{\ell}_L$). Of course, absent the redistributive motive (or ability), we would always have $\ell^*_L \leq \hat{\ell}_L$, and absent the spillover we would always have $\ell^*_L \geq \hat{\ell}_L$.

4 Fiscal federalism during the pandemic

Since the non-cooperative equilibrium is inefficient, there is room for the federal authorities to intervene. In this section I will characterize the tax/transfer policy that would implement the optimal allocation. Since the optimal policy turns out to be rather complex, I will also characterize the effects of a simple policy that redistributes some of the resources towards states with lower level of economic activity.

4.1 Optimal inter-state taxes and transfers

Let $(\tau, T)_t := \left(\tau_{t'}^N, \tau_{t'}^S, T_{t'}^N, T_{t'}^S\right)_{t'=t}^{\infty}$ be the sequence of federal income tax rates and lump-sum transfers imposed on residents of the two regions. The policymaker in each region takes that sequence as given, and the optimization problem is now as follows.

$$W\left(j, Lp_N, Lp_S, (\tau, T)\right) = \max u(c_N) - v(\ell_N) - h(p_N) + \beta\delta W\left(-j, p_N, p_S, (\tau', T')\right)$$

subject to:

$$\begin{aligned}
c_N &\leq \ell_N\left(1 - \tau^N\right) + T^N \\
p_N &\geq \psi_N(j)\, g(\ell_N) + \kappa(Lp_S) \\
p_S &= \pi^S(j, Lp_N)
\end{aligned}$$

The first order condition w.r.t. $\ell_{N,t}$ now implies that the Lagrange multiplier on the epidemiological constraint will equal:

$$\lambda_N(j) = \frac{u'(c_N) - v'(\ell_N)}{\psi_N(j)g'(\ell_N)} - \tau^N \frac{u'(c_N)}{\psi_N(j)g'(\ell_N)}$$

Evaluated at the optimal allocation it becomes:

$$\lambda_N(j) = \lambda_N^*(j) - \tau^N \xi_N^*(j), \qquad \xi_N^*(j) := \frac{u'(c_N^*)}{\psi_N(j)g'(\ell_N^*)}$$

The sequence of taxes and transfers that would implement the optimal allocation, is therefore characterized by the following conditions:

$$\lambda_{N,t}^*(j) = \tau_t^N \xi_{N,t}^*(j) + h'(p_{N,t}^*) + (\beta\delta)^2 \cdot \pi'(p_S^* N, t) \cdot \kappa'(p_{S,t+1}^*)\left(\lambda_{N,t+2}^*(j) - \tau_{t+2}^N \xi_{N,t+2}^*(j)\right) \tag{4.1}$$

$$c_{N,t}^* = \ell_{N,t}^*\left(1 - \tau_t^N\right) + T_t^N \tag{4.2}$$

$$T_t^N + T_t^S = \tau_t^N \ell_{N,t}^* + \tau_t^S \ell_{S,t}^* \tag{4.3}$$

with similar versions of (4.1)-(4.2) for the South.

4.1.1 Long-run optimal taxes

The optimal tax rates that would implement the optimal stationary allocation are easy to derive. In the stationary allocation we will have, for each region $i = N, S$, the following: $\lambda_{i,t}^* = \lambda_{i,t+2}^*$ and $\xi_{i,t}^* = \xi_{i,t+2}^*$.

This yields the following condition that a tax rate imposed on each region $i = N, S$ must satisfy:

$$\begin{aligned}
\tau^i(i) \equiv \tau^H &= \frac{1}{\xi_H^*} \cdot \frac{\beta\delta\kappa'(p_H^*)h'(p_H^*) + (\beta\delta)^2\left(\kappa'(p_H^*) - \pi'_{-i}(p_H^*)\right)\kappa'(p_H^*)\lambda_H^*}{1 - (\beta\delta)^2\pi'_{-i}(p_H^*)\kappa'(p_H^*)} \\
\tau^i(-i) \equiv \tau^L &= \frac{1}{\xi_L^*} \cdot \frac{\beta\delta\kappa'(p_L^*)h'(p_L^*) + (\beta\delta)^2\left(\kappa'(p_L^*) - \pi'_{-i}(p_L^*)\right)\kappa'(p_L^*)\lambda_L^*}{1 - (\beta\delta)^2\pi'_{-i}(p_L^*)\kappa'(p_L^*)} \\
T^s &= c^* - (1-\tau^s)\ell_s^*, \qquad\qquad s = H, L
\end{aligned}$$

Notice that both $\tau^H, \tau^L > 0$, because $\pi'(p) \leq \kappa'(p)$. Additionally, since $\ell_H^* < \ell_L^*$ we will have $c^* > \ell_H^*$ which implies that $T^H > \tau^H \ell_H^* > 0$. A planner would tax employment in a region with high outbreak, but also provide a positive lump-sum transfer to that region in excess of the tax revenue. It also implies, of course, that $T^L < T^H$ and that $T^L < \tau^L \ell_L^*$. We cannot, however, unequivocally determine whether T^L is positive or negative.

Proposition 4.1 (Optimal tax rates in the long-run are higher with strategic considerations)**.** *Let $\tau^s(\mathcal{S})$ and $\tau^s(\mathcal{C})$, $s = H, L$, be the tax rates that implement optimal allocation in the stationary Stackelberg and Cournot equilibria, respectively. Then $\tau^s(\mathcal{S}) > \tau^s(\mathcal{C})$, for $s = H, L$.*

Proof. Pick arbitrary $s = H, L$ and drop the redundant superscripts and subscripts. Comparing the expressions for $\tau(\mathcal{S})$ and $\tau(\mathcal{C})$, we get:

$$\begin{aligned}
\tau(\mathcal{S}) &= \frac{1}{\xi^*} \cdot \frac{\beta\delta\kappa'(p^*)h'(p^*) + (\beta\delta)^2\left(\kappa'(p^*) - \pi'(p^*)\right)\kappa'(p^*)\lambda^*}{1 - (\beta\delta)^2\pi'(p^*)\kappa'(p^*)} \\
\tau(\mathcal{C}) &= \frac{1}{\xi^*} \cdot \frac{\beta\delta\kappa'(p^*)h'(p^*)}{1 - (\beta\delta)^2\kappa'(p^*)^2}
\end{aligned}$$

The result immediately follows from the fact that $\pi'(p^*) < \kappa'(p^*)$. $\square$

4.2 Inter-state redistribution

Finally, consider a simple policy of federal, inter-state redistribution that subsidizes consumption in regions with lower output. Define $\hat{c}_i := \hat{\ell}_i + \tau\left(\hat{\ell}_{-i} - \hat{\ell}_i\right) = (1-\tau)\hat{\ell}_i + \tau\hat{\ell}_{-i}$, where $\tau \in [0, 0.5]$. A perfect inter-state redistribution means that $\tau = 0.5$. If $0 < \tau < 0.5$ the redistribution is partial. Suppose the pandemic hits a country with such scheme. The dynamic program of the policymaker in the North is now as follows:

$$W(j, Lp_N, Lp_S) = \max u(c_N) - v(\ell_N) - h(p_N) + \beta\delta W(-j, p, p_S)$$

subject to:

$$
\begin{aligned}
&c_N \leq (1-\tau)\cdot \ell_N + \tau \cdot \ell_S(j, Lp_N)\\
&p_N \geq \psi_N(j) g(\ell) + \kappa(Lp_S)\\
&p_S \geq \pi^S(j, Lp_N)
\end{aligned}
$$

The inter-state redistribution has a non-trivial impact on the incentives faced by the two policymakers. Most importantly, each policymaker is now more inclined to impose more restrictive policies (i.e. reduce ℓ). This is because, given the action of the other policymaker, reducing ℓ by one, will reduce c only by $(1-\tau) < 1$.

The inter-temporal condition for the policymaker in the North will now take the following form[1] :

$$
\begin{aligned}
\lambda_{N,t}(j) = {} & h'(p_{N,t}) + (\beta\delta)^2 \pi'_S(p_{N,t}) \cdot \kappa'(p_{S,t+1}) \cdot \lambda_{N,t+2}(j) + \\
& - \tau \cdot \beta\delta \cdot u'(c_{N,t+1}) \cdot \ell'_S(p_{N,t}) \\
& + \tau \cdot \left[\frac{u'(c_{N,t})}{\psi_N(j) g'(\ell_{N,t})} - \frac{u'(c_{N,t+2})}{\psi_N(j) g'(\ell_{N,t+2})} \cdot (\beta\delta)^2 \cdot \pi'_S(p_{N,t}) \cdot \kappa'(p_{S,t+1}) \right]
\end{aligned}
$$

where $\lambda_{N,t}(j) = \frac{u'(c_{N,t}) - v'(\ell_{N,t})}{\psi_N(j) g'(\ell_{N,t})}$.[2] Comparing the expression above with (3.2)-(3.3) we can see that, starting at $\tau = 0$, an increase in τ brings the non-cooperative allocation closer to the optimum. The first line is identical to (3.3).

The second line takes into account the strategic consideration that reducing $p_{N,t}$ today will incentivize the policymaker in the South to ease their restrictions and increase $\ell_{S,t+1}$ which will then increase $c_{N,t+1}$ by $\tau \cdot \Delta \ell_{S,t+1}$. The benefit of that is the marginal utility of consumption next period, discounted by $\beta\delta$. In the Cournot equilibrium, of course, that line disappears.

The last line is the most subtle. Since $c_N = \ell_N + \tau(\ell_S - \ell_N)$, an increase in ℓ_N has two effects. The first is the benefit in form of higher consumption. That benefit, net of the disutility from labor, and divided by the implied change in p_N is captured by λ_N on the left-hand side. The second effect is the cost of reducing the federal transfer received (or increasing the federal transfer paid). That cost, divided by the implied change in p_N, is given by $\tau \cdot \frac{u'(c_N)}{\psi_N g'(\ell_N)}$, the first term on the last line. We can thus interpret that term as the additional benefit of a more tighter restriction in period t in the form of an increase in net federal transfer. Such tighter restriction, however, will lead to a lower $p_{N,t}$, which reduces $p_{S,t+1}$, which in turn reduces the

[1] See Appendix A.3 for all derivations and proofs.

[2] Note that this time $\lambda_{N,t}(j)$ is not the multiplier on the epidemiological constraint, which instead is given by $\tilde{\lambda}_{N,t}(j) = \frac{(1-\tau)u'(c_{N,t}) - v'(\ell_{N,t})}{\psi_N(j) g'(\ell_{N,t})}$.

size of externality the North would face in period $t+2$ — the effect captured by $\pi'_S(p_{N,t}) \cdot \kappa'(p_{S,t+1})$. The lower size of externality will incentivize the policymaker to ease the restrictions and increase labor supply, the cost of which is captured by $\tau \cdot \frac{u'(c_N)}{\psi_N g'(\ell_N)}$ in period $t+2$, discounted by $(\beta\delta)^2$. Hence, the last line captures the benefit of higher net federal transfer today minus the cost of the lower net federal transfer two periods from today. Appendix A.3 shows that if $\frac{v'}{g'}$ is non-decreasing in ℓ, the term in brackets is positive.

The stationary equilibrium allocation now needs to satisfy the following condition if $\psi = \psi^H$:

$$\frac{u'(c_H) - v'(\ell_H)}{\psi^H g'(\ell_H)} = \frac{h'(p_H)}{1-(\beta\delta)^2 \cdot \kappa'(p_H) \cdot \pi'(p_H)} + \tau \cdot \left[\frac{u'(c_H)}{\psi^H g'(\ell_H)} + \frac{\beta\delta \cdot u'(c_L) \cdot \frac{\kappa'(p_H)-\pi'(p_H)}{\psi^H g'(\ell_H)}}{1-(\beta\delta)^2 \cdot \pi'(p_H) \cdot \kappa'(p_H)} \right],$$

with a similar one when $\psi = \psi^L$. Notice that the extra term the right-hand side is positive if and only if $\tau > 0$. Notice also that the impact of the inter-state redistribution is stronger in the Stackelberg equilibrium, because $\kappa' - \pi' > 0$ (that term equals zero in the Cournot equilibrium). In the Stackelberg equilibrium, under federal redistribution, the policymaker knows that the federal government will move resources towards the region with smaller output. Therefore, the incentive to pass the cost of battling an outbreak towards the other region is now reduced - the more the other region lowers its output, the more my region will have to pay for it. In other words, the existence of the inter-state redistribution creates a race-to-the-bottom type response, similar to the one we know from the tax competition literature (Wilson, 1986; Janeba and Wilson, 2011; Chirinko and Wilson, 2017).

In general, the inter-state redistribution moves the stationary equilibrium towards the optimal allocation in the sense that $\hat{\ell}_H$ with redistribution is smaller than without. The redistribution alone, however, will not implement the optimal allocation, unless $\psi^H = \psi^L$. The reason is that in the optimal allocation we have $c_H = c_L = c^* = \frac{1}{2}\ell^* H + \frac{1}{2}\ell^*_L$ so we would need to have $\tau = 0.5$ which will only work in special cases. If $\psi^H = \psi^L$, i.e. if the two regions are identical, one can find the level of strategic redistribution scheme that will implement the optimal allocation. Interestingly, in equilibrium, no region will receive a transfer, because they will both choose the same level of employment. Proposition 4.2 formalizes those results.

Proposition 4.2. *Let $\hat{z}(\mathcal{C};\tau_C)$ and $\hat{z}(\mathcal{S};\tau_S)$ be the stationary non-cooperative allocations in the Cournot and Stackelberg equilibria with inter-state redistribution of τ_C and τ_S, respectively, and let z^* be the optimal allocation, with a similar notation for individual elements. Then there exist $\hat{\tau}_C > \hat{\tau}_S > 0$ such that $\hat{z}(\mathcal{S};\hat{\tau}_S) = \hat{z}(\mathcal{C};\hat{\tau}_C) = z^*$ if and only if $\psi^H = \psi^L$*

Proof. See Appendix A.3.2. □

Notice that, since the strategic redistribution has more bite in the Stackelberg equilibrium, the size of τ required to implement the stationary optimal allocation in the symmetric world is smaller in that environment. In other words, federal redistribution can be more effective in curtailing the pandemic in the presence of strategic interactions between the regions.

5 Summary and conclusions

In this paper, I analyzed the inefficiencies that arise during an uncoordinated response to a disease outbreak severe enough to warrant state-imposed limits on economic activity. In the presence of inter-regional spillovers, the non-cooperative allocation is inefficient for at least two reasons. First, regional policymakers may not put sufficient weight on other regions' welfare. Second, they can free-ride on restrictions implemented in other regions.

When combined with strong empirical evidence of significant epidemiological spillovers across the U.S. states (Rothert et al., 2020; Brinkman and Mangum, 2020) and between countries (Eckardt et al., 2020), the results in this paper emphasize the important role that the federal governments in countries like the U.S. can and should play in curbing the pandemic. They are also important when, in the future, different countries and states will be judged by researchers on their successes and failures in containing the spread of Covid-19.

The paper offers a fairly intuitive and flexible framework that can serve as a starting point for further analysis of policy responses to disease outbreaks in a world with inter-connected regions. Possible extensions, left for further research, could include economic externalities (via e.g. the presence of production networks as in Acemoglu et al. (2012)), uncertainty and learning about the relative importance of local transmission vs. inter-regional spillovers, or uncertainty and learning about the arrival and effectiveness of a vaccine.

As the countries around the world struggle to contain the second wave of Covid-19, it becomes apparent that almost no place is an island. While the exact response policies are decided by individual countries or, as in the United States, by local governors, the effects of these policies transcend national and state borders. An uncoordinated policy response, and even an inconsistent messaging across states on simple precautionary measures such as mask-wearing, exacerbate the outbreak.

References

Acemoglu, D., V. M. Carvalho, A. Ozdaglar, and A. Tahbaz-Salehi (2012): "The Network Origins of Aggregate Fluctuations," *Econometrica*, 80, 1977–2016.

Allcott, H., L. Boxell, J. C. Conway, M. Gentzkow, M. Thaler, and D. Y. Yang (2020): "Polarization and Public Health: Partisan Differences in Social Distancing during the Coronavirus Pandemic," Working Paper 26946, National Bureau of Economic Research.

Beck, T. and W. Wagner (2020): "National containment policies and international cooperation," *Covid Economics*, 8, 120–134.

Brinkman, J. and K. Mangum (2020): "The Geography of Travel Behavior in the Early Phase of the COVID-19 Pandemic," Working Papers 20-38, Federal Reserve Bank of Philadelphia.

Chirinko, R. S. and D. J. Wilson (2017): "Tax competition among U.S. states: Racing to the bottom or riding on a seesaw?" *Journal of Public Economics*, 155, 147–163.

Dave, D. M., A. I. Friedson, D. McNichols, and J. J. Sabia (2020): "The Contagion Externality of a Superspreading Event: The Sturgis Motorcycle Rally and COVID-19," Working Paper 27813, National Bureau of Economic Research.

Eckardt, M., K. Kappner, and N. Wolf (2020): "Covid-19 across European Regions: the Role of Border Controls," Working Paper DP15178, Center for Economic and Policy Research.

Janeba, E. and J. D. Wilson (2011): "Optimal fiscal federalism in the presence of tax competition," *Journal of Public Economics*, 95, 1302–1311.

Kuchler, T., D. Russel, and J. Stroebel (2020): "The Geographic Spread of COVID-19 Correlates with the Structure of Social Networks as Measured by Facebook," Working Paper 26990, National Bureau of Economic Research.

Painter, M. and T. Qiu (2020): "Political Beliefs affect Compliance with COVID-19 Social Distancing Orders," *Covid Economics*, 4.

Rothert, J. (2020): "Optimal federal redistribution during the uncoordinated response to a pandemic," Departmental Working Papers 64, United States Naval Academy Department of Economics.

Rothert, J., R. Brady, and M. Insler (2020): "The Fragmented United States of America: The impact of scattered lock-down policies on country-wide infections," *Covid Economics*, 43, 42–95.

Wilson, J. D. (1986): "A theory of interregional tax competition," *Journal of Urban Economics*, 19, 296–315.

A Derivations and proofs

A.1 Section 3 - optimal vs. equilibrium outcomes

Non-cooperative allocation

The dynamic program for a policy-maker in the North in the non-cooperative allocation is:

$$W(i, Lp_N, Lp_S) = \max_{\ell,p} u(\ell) - v(\ell) - h\,(p) + \beta\left[\delta W(-i, p, p_S) + (1-\delta)V^R\right]$$

subject to:

$$p \geq \psi_N(i) \cdot g(\ell) + \kappa\,(Lp_S)$$

$$p_S \geq \pi_S\,(i, Lp_N)$$

First order conditions:

$$\text{w.r.t. } \ell: \quad 0 = -v'(\ell) + u'(\ell) - \lambda_N(i) \cdot \psi_N(i) g'(\ell) \tag{A.1}$$

$$\text{w.r.t. } p: \quad 0 = -h'(p) + \beta\delta \cdot W_N(-i, p, p_S) + \lambda_N(i) \tag{A.2}$$

$$\text{w.r.t. } p_S: \quad 0 = \beta\delta \cdot W_S(-i, p, p_S) + \lambda_S(i) \tag{A.3}$$

Envelope conditions:

$$\text{w.r.t. } Lp_N: \quad 0 = -W_N(i, Lp_N, Lp_S) - \lambda_S(i) \cdot \pi'_S(i, Lp_N)$$

$$\text{w.r.t. } Lp_S: \quad 0 = -W_S(i, Lp_N, Lp_S) - \lambda_N(i) \cdot \kappa'(Lp_S)$$

Even though the problem is written recursively, in order to avoid confusion between derivatives and the values of Lagrange multipliers in subsequente periods, I will keep the time subscripts from now on. The two envelope conditions yield:

$$W_N(i, p_{N,t-1}, p_{S,t-1}) = -\lambda_{S,t}(i) \cdot \pi'_S(i, p_{N,t-1})$$

$$W_S(i, p_{N,t-1}, p_{S,t-1}) = -\lambda_{N,t}(i) \cdot \kappa'(p_{S,t-1})$$

and, therefore:

$$W_N(-i, p_{N,t}, p_{S,t}) = -\lambda_{S,t+1}(-i) \cdot \pi'_S(-i, p_{N,t}) \tag{A.4}$$

$$W_S(-i, p_{N,t}, p_{S,t}) = -\lambda_{N,t+1}(-i) \cdot \kappa'(p_{S,t}) \tag{A.5}$$

First order condition (A.2) can now be written as:

$$\lambda_{N,t}(i) = h'(p_{N,t}) - \beta\delta \cdot W_N(-i, p_{N,t}, p_{S,t}) = h'(p_{N,t}) + \pi'_S(-i, p_{N,t}) \cdot \beta\delta \cdot \lambda_{S,t+1}(-i)$$

First order condition (A.3), combined with (A.5) then imply that we will have:

$$\lambda_{S,t+1}(-i) = -\beta\delta \cdot W_S(i, p_{N,t+1}, p_{S,t+1}) = \beta\delta \cdot \lambda_{N,t+2}(i) \cdot \kappa'(p_{S,t+1})$$

So we end up with condition (3.2):

$$\lambda_{N,t}(i) = h'(p_{N,t}) + \pi'_S(-i, p_{N,t}) \cdot (\beta\delta)^2 \cdot \kappa'(p_{S,t+1}) \cdot \lambda_{N,t+2}(i)$$

Optimal allocation

The dynamic program of the social planner is:

$$V\left(j, Lp_N, Lp_S\right) = \max_{c_i, \ell_i, p_i} \sum_{i \in \{S,N\}} \left[u(c_i) - v(\ell_i) - h(p_i)\right] + \beta \left[\delta V(-j, p_N, p_S) + (1-\delta)V^R\right]$$

subject to:

$$\ell_N + \ell_S \geq c_N + c_S$$

$$p_i \geq \psi_i(j) g(\ell_i) + \kappa(Lp_{-i}), \qquad i = N, S$$

First order conditions:

$$\text{w.r.t. } c_i: \quad 0 = u'(c_i^*) - \mu \qquad \Rightarrow \qquad c_N^* = c_S^* = c^* \tag{A.6}$$

$$\text{w.r.t. } \ell_i: \quad 0 = -v'(\ell_i^*) + u'(c^*) - \lambda_i(j) \cdot \psi_i(j) g'(\ell_i^*) \tag{A.7}$$

$$\text{w.r.t. } p_i: \quad 0 = -h'(p_i) + \beta\delta \cdot V_i(-j, p_i, p_{-i}) + \lambda_i(j) \tag{A.8}$$

Envelope conditions:

$$\text{w.r.t. } Lp_i: \quad 0 = -V_i(j, Lp_i, Lp_{-i}) - \lambda_{-i}(j) \cdot \kappa'(Lp_i)$$

The Envelope condition for the two regions in period $t+1$ become:

$$V_N(-j, p_{N,t}, p_{S,t}) = -\lambda_{S,t+1}(-j) \cdot \kappa'(p_{N,t})$$
$$V_S(-j, p_{N,t}, p_{S,t}) = -\lambda_{N,t+1}(-j) \cdot \kappa'(p_{S,t})$$

First order condition (A.8) can now be written as:

$$\lambda_{N,t}(j) = h'(p_{N,t}) - \beta\delta \cdot V_N(-j, p_{N,t}, p_{S,t}) = h'(p_{N,t}) + \beta\delta \cdot \lambda_{S,t+1}(-j) \cdot \kappa'(p_{N,t})$$
$$\lambda_{S,t}(j) = h'(p_{S,t}) - \beta\delta \cdot V_S(-j, p_{N,t}, p_{S,t}) = h'(p_{S,t}) + \beta\delta \cdot \lambda_{N,t+1}(-j) \cdot \kappa'(p_{S,t})$$

Setting $\lambda_{S,t+1}(-j) = h'(p_{S,t+1}) + \beta\delta \cdot \lambda_{N,t+2}(j) \cdot \kappa'(p_{S,t+1})$, and plugging back into the expression for $\lambda_{N,t}(j)$ above, we get condition (3.2):

$$\lambda_{N,t}(j) = h'(p_{N,t}) + \beta\delta \cdot \kappa'(p_{N,t}) \cdot [h'(p_{S,t+1}) + \beta\delta \cdot \lambda_{N,t+2}(j) \cdot \kappa'(p_{S,t+1})]$$

A.2 Proof of Proposition 3.1

1. It is enough to show that $\hat{\ell}_H > \ell^*_H$, from which it immediately follows that $\hat{p}_H > p^*_H$ and $\hat{c}_H > c^*$. The equations that characterize the optimal and non-cooperative stationary allocations can be written as:

$$u'\left(\frac{\ell^*_H + \ell^*_L}{2}\right) = v'\left(\ell^*_H\right) + \psi^H g'\left(\ell^*_H\right) \frac{h'(p^*_H)(1 + \beta\delta \cdot \kappa'(p^*_H))}{1 - (\beta\delta)^2 \kappa'(p^*_H)^2} \qquad \text{optimal}$$
$$u'\left(\hat{\ell}_H\right) = v'\left(\hat{\ell}_H\right) + \psi^H g'\left(\hat{\ell}_H\right) \frac{h'(\hat{p}_H)}{1 - (\beta\delta)^2 \kappa'(\hat{p}_H) \cdot \pi'_L(\hat{p}_H)} \qquad \text{non-cooperative}$$

Suppose that $\hat{\ell}_H \leq \ell^*_H$. Since $\ell^*_L > \ell^*_H$ it then follows that $u'\left(\frac{\ell^*_H + \ell^*_L}{2}\right) < u'\left(\hat{\ell}_H\right)$. However, the right hand side of the two equations above are strictly increasing in ℓ_H. Moreover, for every value ℓ_H the right hand side of the equation that characterizes optimal allocation is always larger than of the one that characterizes the non-cooperative allocation, because $\pi'_L(p) < \kappa'(p)$. This would then imply that:

$$v'\left(\ell^*_H\right) + \psi^H g'\left(\ell^*_H\right) \frac{h'(p^*_H)(1 + \beta\delta \cdot \kappa'(p^*_H))}{1 - (\beta\delta)^2 \kappa'(p^*_H)^2} > v'\left(\hat{\ell}_H\right) + \psi^H g'\left(\hat{\ell}_H\right) \frac{h'(\hat{p}_H)}{1 - (\beta\delta)^2 \kappa'(\hat{p}_H) \cdot \pi'_L(\hat{p}_H)}$$

while, at the same time:

$$u'\left(\frac{\ell^*_H + \ell^*_L}{2}\right) < u'\left(\hat{\ell}_H\right),$$

which is a contradiction.

2. Setting $\kappa' = 0$, the equations characterizing optimal and non-cooperative stationary allocations are:

$$u'\left(\frac{\ell_H^* + \ell_L^*}{2}\right) = v'\left(\ell_j^*\right) + h'\left(\psi^j g\left(\ell_j^*\right)\right)\psi^j g'\left(\ell_j^*\right) \qquad \text{optimal}$$
$$u'\left(\hat{\ell}_j\right) = v'\left(\hat{\ell}_j\right) + h'\left(\psi^j g\left(\hat{\ell}_j\right)\right)\psi^j g'\left(\hat{\ell}_j\right) \qquad \text{non-cooperative}$$

   where $j = H, L$ and $\psi^L < \psi^H$. From the first part we know that, regardless of $\kappa(\cdot)$, we will have $\ell_H^* < \hat{\ell}_H < \hat{\ell}_L$. Suppose then, that $\ell_L^* \leq \ell_L$, which implies that $c^* < \hat{\ell}_L$. We then get that:

$$u'(c^*) > u'(\hat{\ell}_L)$$

   while at the same time having:

$$v'\left(\ell_L^*\right) + h'\left(\psi^L g\left(\ell_L^*\right)\right)\psi^L g'\left(\ell_L^*\right) \leq v'\left(\hat{\ell}_L\right) + h'\left(\psi^L g\left(\hat{\ell}_L\right)\right)\psi^L g'\left(\hat{\ell}_L\right),$$

   which is a contradiction.

3. Follows immediately from the fact that $\pi'(p) < \kappa'(p)$.

A.3 Section 4.2 - inter-state redistribution

The dynamic program is:

$$W(i, Lp_N, Lp_S) = \max u(c) - v(\ell) - h(p) + \beta\delta W(-i, p, p_S)$$

subject to:

$$c \leq (1-\tau)\cdot\ell + \tau\ell_S(i, Lp_N)$$
$$p \geq \psi_N(i)g(\ell) + \kappa(Lp_S)$$
$$p_S \geq \pi_S(i, Lp_N)$$

First order conditions:

$$\text{w.r.t. } c: \quad 0 = u'(c) - \mu \tag{A.9}$$
$$\text{w.r.t. } \ell: \quad 0 = -v'(\ell) + u'(c)\cdot(1-\tau) - \lambda_N(i)\cdot\psi_N(i)g'(\ell) \tag{A.10}$$
$$\text{w.r.t. } p: \quad 0 = -h'(p) + \beta\delta\cdot W_N(-i, p, p_S) + \lambda_N(i) \tag{A.11}$$
$$\text{w.r.t. } p_S: \quad 0 = \beta\delta\cdot W_S(-i, p, p_S) + \lambda_S(i) \tag{A.12}$$

Envelope conditions:

$$\text{w.r.t. } Lp_N: \quad 0 = -W_N(i, Lp_N, Lp_S) + \tau \cdot u'(c) \cdot \ell'_S(i, Lp_N) - \lambda_S(i) \cdot \pi'_S(i, Lp_N) \tag{A.13}$$

$$\text{w.r.t. } Lp_S: \quad 0 = -W_S(i, Lp_N, Lp_S) - \lambda_N(i) \cdot \kappa'(Lp_S) \tag{A.14}$$

The Envelope conditions in period $t+1$ can be written as:

$$W_N(-i, p_{N,t}, p_{S,t}) = \tau \cdot u'(c_{N,t+1}) \cdot \ell'_S(-i, p_{N,t}) - \lambda_{S,t+1}(-i) \cdot \pi'_S(-i, p_{N,t}) \tag{A.15}$$

$$W_S(-i, p_{N,t}, p_{S,t}) = -\lambda_{N,t+1}(-i) \cdot \kappa'(p_{S,t}) \tag{A.16}$$

Plug it into the first-order condition A.11, we get the following expression for the North:

$$\begin{aligned}
\lambda_{N,t}(i) &= h'(p_{N,t}) - \beta\delta \cdot W_N(-i, p_{N,t}, p_{S,t}) = \\
&= h'(p_{N,t}) - \beta\delta \cdot [\tau \cdot u'(c_{N,t+1}) \cdot \ell'_S(-i, p_{N,t}) - \lambda_{S,t+1}(-i) \cdot \pi'_S(-i, p_{N,t})]
\end{aligned}$$

From (A.12) we know that $\lambda_{S,t+1}(-i) = -\beta\delta \cdot W_S(i, p_{N,t+1}, p_{S,t+1})$ so we get:

$$\begin{aligned}
\lambda_{N,t}(i) &= h'(p_{N,t}) - \beta\delta \cdot [\tau \cdot u'(c_{N,t+1}) \cdot \ell'_S(-i, p_{N,t}) + \pi'_S(-i, p_{N,t}) \cdot \beta\delta \cdot W_S(i, p_{N,t+1}, p_{S,t+1})] = \\
&= h'(p_{N,t}) - \beta\delta \cdot [\tau \cdot u'(c_{N,t+1}) \cdot \ell'_S(-i, p_{N,t}) - \pi'_S(-i, p_{N,t}) \cdot \beta\delta \cdot \lambda_{N,t+2}(i) \cdot \kappa'(p_{S,t+1})]
\end{aligned}$$

where the second equality follows from (A.16). Define $\tilde{\lambda}_{N,t}(i) = \frac{u'(c_{N,t}) - v'(\ell_{N,t})}{\psi_N(i) g'(\ell_{N,t})}$ and using (A.10) we get:

$$\lambda_{N,t}(i) = \tilde{\lambda}_{N,t}(i) - \tau \frac{u'(c_{N,t})}{\psi_N(i) g'(\ell_{N,t})}$$

We can then write:

$$\begin{aligned}
\tilde{\lambda}_{N,t}(i) &= h'(p_{N,t}) + \tau \frac{u'(c_{N,t})}{\psi_N(i) g'(\ell_{N,t})} - \beta\delta \cdot \tau \cdot u'(c_{N,t+1}) \cdot \ell'_S(-i, p_{N,t}) \\
&\quad + \pi'_S(-i, p_{N,t}) \cdot \kappa'(p_{S,t+1}) \cdot (\beta\delta)^2 \cdot \left[\tilde{\lambda}_{N,t+2}(i) - \tau \frac{u'(c_{N,t+2})}{\psi_N(i) g'(\ell_{N,t+2})}\right]
\end{aligned}$$

which becomes:

$$\begin{aligned}
\tilde{\lambda}_{N,t}(i) &= h'(p_{N,t}) + \tau \frac{u'(c_{N,t})}{\psi_N(i) g'(\ell_{N,t})} - \beta\delta \cdot \tau \cdot u'(c_{N,t+1}) \cdot \ell'_S(-i, p_{N,t}) \\
&\quad + \pi'_S(-i, p_{N,t}) \cdot \kappa'(p_{S,t+1}) \cdot (\beta\delta)^2 \cdot \tilde{\lambda}_{N,t+2}(i) \\
&\quad - \pi'_S(-i, p_{N,t}) \cdot \kappa'(p_{S,t+1}) \cdot (\beta\delta)^2 \cdot \tau \frac{u'(c_{N,t+2})}{\psi_N(i) g'(\ell_{N,t+2})}
\end{aligned}$$

Evaluate at the optimal allocation and subtract (3.2) from both the left- and the right-hand sides, we will get, in the Stackelberg allocation:

$$0 = \tau \frac{u'(c_t^*)}{\psi_N(i) g'(\ell_{N,t}^*)} - \beta\delta \cdot \tau \cdot u'(c_{t+1}^*) \cdot \ell_S'(-i, p_{N,t}^*) - \beta\delta\kappa'(p_{N,t}^*) h'(p_{S,t+1}^*) - \pi_S'(-i, p_{N,t}^*) \cdot \kappa'(p_{S,t+1}^*) \cdot (\beta\delta)^2 \cdot \tau \frac{u'(c_{t+2}^*)}{\psi_N(i) g'(\ell_{N,t+2}^*)}$$

and, in the Cournot allocation:

$$0 = \tau \frac{u'(c_t^*)}{\psi_N(i) g'(\ell_{N,t}^*)} - \beta\delta\kappa'(p_{N,t}^*) h'(p_{S,t+1}^*)$$

A.3.1 Long-Run Outcomes

To derive the long-run outcomes under strategic redistribution, we drop the time subscripts to get the following, for a region with $\psi = \psi^H$:

$$\begin{aligned} \tilde{\lambda}_H(i) = & \, h'(p_H) + \tau \frac{u'(c_H)}{\psi^H g'(\ell_H)} - \beta\delta \cdot \tau \cdot u'(c_L) \cdot \ell_S'(p_H) \\ & + \pi_S'(p_H) \cdot \kappa'(p_H) \cdot (\beta\delta)^2 \cdot \tilde{\lambda}_H(i) \\ & - \pi_S'(p_H) \cdot \kappa'(p_H) \cdot (\beta\delta)^2 \cdot \tau \frac{u'(c_H)}{\psi^H g'(\ell_H)} \end{aligned}$$

Next, we get:

$$\begin{aligned} \tilde{\lambda}_H(i) \cdot \left[1 - (\beta\delta)^2 \cdot \pi_S'(p_H) \cdot \kappa'(p_H)\right] = & \, h'(p_H) - \beta\delta \cdot \tau \cdot u'(c_L) \cdot \ell_S'(p_H) \\ & + \left[1 - (\beta\delta)^2 \cdot \pi_S'(p_H) \cdot \kappa'(p_H)\right] \tau \frac{u'(c_H)}{\psi^H g'(\ell_H)} \end{aligned}$$

which yields:

$$\frac{u'(c_H) - v'(\ell_H)}{\psi^H g'(\ell_H)} = \frac{h'(p_H) - \beta\delta \cdot \tau \cdot u'(c_L) \cdot \ell_S'(p_H)}{1 - (\beta\delta)^2 \cdot \pi_S'(p_H) \cdot \kappa'(p_H)} + \tau \frac{u'(c_H)}{\psi^H g'(\ell_H)}$$

which can be written as:

$$\frac{u'(c_H) - v'(\ell_H)}{\psi^H g'(\ell_H)} = \frac{h'(p_H)}{1 - (\beta\delta)^2 \cdot \kappa'(p_H) \cdot \pi_S'(p_H)} + \frac{\beta\delta \cdot \tau \cdot u'(c_L) \cdot (\kappa'(p_H) - \pi_S'(p_H))}{1 - (\beta\delta)^2 \cdot \pi_S'(p_H) \cdot \kappa'(p_H)} + \tau \frac{u'(c_H)}{\psi^H g'(\ell_H)}$$

and then as:

$$\frac{u'(c_H) - v'(\ell_H)}{\psi^H g'(\ell_H)} = \frac{h'(p_H)}{1 - (\beta\delta)^2 \cdot \kappa'(p_H) \cdot \pi'(p_H)} + \tau \cdot \left[\frac{u'(c_H)}{\psi^H g'(\ell_H)} + \frac{\beta\delta \cdot u'(c_L) \cdot \frac{\kappa'(p_H) - \pi'(p_H)}{\psi^H g'(\ell_H)}}{1 - (\beta\delta)^2 \cdot \pi'(p_H) \cdot \kappa'(p_H)}\right]$$

A.3.2 Proof of Proposition 4.2

Proof of the "if" direction Suppose that $\psi^H = \psi^L = \psi$. Then $x_H^* = x_L^* = x^*$, $x \in \{c, \ell, p\}$. Then τ_C is defined as:

$$\tau_C = \frac{\psi g'(\ell^*)}{u'(c^*)} \frac{h'(p^*) \cdot \beta\delta \cdot \kappa'(p^*)}{1 - (\beta\delta)^2 \kappa'(p^*)^2} > 0.$$

Next, τ_S must satisfy:

$$\tau_S \cdot \left[\frac{u'(c^*)}{\psi g'(\ell^*)} + \frac{\beta\delta \cdot u'(c^*) \cdot \frac{\kappa'(p^*)-\pi'(p^*)}{\psi g'(\ell^*)}}{1-(\beta\delta)^2 \cdot \pi'(p^*) \cdot \kappa'(p^*)} \right] = \frac{h'(p^*) \cdot \beta\delta \cdot \kappa'(p^*)}{1-(\beta\delta)^2 \kappa'(p^*)^2}$$

which can be written as:

$$\tau_S \cdot \frac{u'(c^*)}{\psi g'(\ell^*)} \left[1 + \frac{\beta\delta \cdot (\kappa'(p^*) - \pi'(p^*))}{1-(\beta\delta)^2 \cdot \pi'(p^*) \cdot \kappa'(p^*)} \right] = \frac{h'(p^*) \cdot \beta\delta \cdot \kappa'(p^*)}{1-(\beta\delta)^2 \kappa'(p^*)^2}$$

which yields:

$$\tau_C = \frac{\psi g'(\ell^*)}{u'(c^*)} \frac{h'(p^*) \cdot \beta\delta \cdot \kappa'(p^*)}{1-(\beta\delta)^2 \kappa'(p^*)^2} > \frac{1}{1+\frac{\beta\delta\cdot(\kappa'(p^*)-\pi'(p^*))}{1-(\beta\delta)^2\cdot\pi'(p^*)\cdot\kappa'(p^*)}} \frac{\psi g'(\ell^*)}{u'(c^*)} \frac{h'(p^*) \cdot \beta\delta \cdot \kappa'(p^*)}{1-(\beta\delta)^2 \kappa'(p^*)^2} = \tau_S > 0$$

$\square$

Proof of the "only if" direction Suppose (WLOG) that $\psi^H > \psi^L$. Then $\ell_H^* < \ell_L^*$ and $c^* = \frac{1}{2}\ell_H^* + \frac{1}{2}\ell_L^*$. The only value of τ that could then implement the optimal allocation would be $\tau = \frac{1}{2}$. Suppose then that $\tau = \frac{1}{2}$. In the Cournot equilibrium this would imply that:

$$\frac{1}{2} \cdot u'(c^*) = \psi^j g'(\ell_j^*) \frac{h'(p_j^*) \cdot \beta\delta \cdot \kappa'(p_j^*)}{1-(\beta\delta)^2 \kappa'(p_j^*)^2}, \qquad j = H, L$$

Suppose then, that the expression above is true for some combination of β, δ, $g(\cdot)$, $u(\cdot)$, $h(\cdot)$, $\kappa(\cdot)$, and for $\psi = \psi^H$. It remains to show that it cannot hold when $\psi = \psi^L$. Then we have:

$$\psi^H g'(\ell_H^*) \frac{h'(p_H^*) \cdot \beta\delta \cdot \kappa'(p_H^*)}{1-(\beta\delta)^2 \kappa'(p_H^*)^2} = \psi^L g'(\ell_L^*) \frac{h'(p_L^*) \cdot \beta\delta \cdot \kappa'(p_L^*)}{1-(\beta\delta)^2 \kappa'(p_L^*)^2}$$

We know that stationary optimal allocation must satisfy:

$$\frac{u'(c^*) - v'\left(\ell_j^*\right)}{\psi^j g'\left(\ell_j^*\right)} = \frac{h'(p_j^*)}{1-(\beta\delta)^2 \kappa'(p_j^*)^2} + \frac{h'(p_j^*) \cdot \beta\delta \cdot \kappa'(p_j^*)}{1-(\beta\delta)^2 \kappa'(p_j^*)^2}, \quad j = H, L$$

which is equivalent to:

$$u'(c^*) - v'\left(\ell_j^*\right) = \psi^j g'\left(\ell_j^*\right) \frac{h'(p_j^*)}{1-(\beta\delta)^2 \kappa'(p_j^*)^2} + \psi^j g'\left(\ell_j^*\right) \frac{h'(p_j^*) \cdot \beta\delta \cdot \kappa'(p_j^*)}{1-(\beta\delta)^2 \kappa'(p_j^*)^2}, \quad j = H, L$$

Subtract both sides of the equation above for $j = L$ from that same equation for $j = H$ and we get:

$$v'(\ell_L^*) - v'(\ell_H^*) = \psi^H g'(\ell_H^*) \frac{h'(p_H^*)}{1-(\beta\delta)^2 \kappa'(p_H^*)^2} - \psi^L g'(\ell_L^*) \frac{h'(p_L^*)}{1-(\beta\delta)^2 \kappa'(p_L^*)^2}$$

Since $v'(\ell_L^*) - v'(\ell_H^*) > 0$, then

$$\psi^H g'\left(\ell_H^*\right) \frac{h'(p_H^*)}{1 - \left(\beta\delta\right)^2 \kappa'(p_H^*)^2} > \psi^L g'\left(\ell_L^*\right) \frac{h'(p_L^*)}{1 - \left(\beta\delta\right)^2 \kappa'(p_L^*)^2}$$

Since $p_H^* > p_L^*$ we then get:

$$\psi^H g'\left(\ell_H^*\right) \frac{h'(p_H^*)\beta\delta\kappa'(p_H^*)}{1 - \left(\beta\delta\right)^2 \kappa'(p_H^*)^2} > \psi^L g'\left(\ell_L^*\right) \frac{h'(p_L^*)\beta\delta\kappa'(p_L^*)}{1 - \left(\beta\delta\right)^2 \kappa'(p_L^*)^2}$$

which is a contradiction.