Preparing for Industrial Input Shortages*

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Abstract

Why do private incentives distort investment in resilience? I build on Grossman, Helpman and Lhuillier (2023) to model agents' investment in excess capacity of a homogeneous good, for example electricity, computing power, or semi-conductors. During shortages the marginal value of the good varies across agents, which distorts investment in excess capacity of the good. A secondary market for the homogeneous good would improve this misallocation; however, private incentives may cause the market price to be higher than would be socially optimal. I use this framework to evaluate policy solutions to create an efficient secondary market. In ongoing work, I will look for a mechanism to achieve the optimal allocation. This model provides a unified theory to compare the problem of optimal hospital surge capacity, bank liquidity buffers, and producer inventory. In Lewis-Hayre (2024), I apply the model to a novel situation: supply chain disruptions.

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1 Introduction

Since the 10th century A.D., from the Iberian Peninsula to New Mexico, people have relied on communal irrigation systems called acequias. When water is abundant, acequias seem like any other irrigation system: its users extract water until the marginal value of water aligns with the marginal cost of using the water; however, during shortages, acequias allow a majordomo, a town official, to efficiently allocate water between residents. As such, this mechanism incentivizes cooperation to invest in acequias, which better capture snow melt, thereby promoting water adequacy. A drawback of acequias is that the majordomo must determine how to allocate water during shortages. How can policy incentivize these benefits of the acequia without the need for a majordomo?

A similar problem arises in shortages of homogeneous goods in industrial settings. The prospect of shortages of electricity, hospital equipment, cloud computing resources, and semi-conductors, has led governments to deem securing access to these goods a matter of national security. As such, governments have resorted to an industrial policy to secure access to critical goods. For example, the United States Government, between executive action, the Defense Production Act, and The CHIPS and Science Act, has invested in nuclear energy, personal protective equipment, cybersecurity, and semi-conductor factories.

Electricity, surgical masks, bank reserves, computing power, and semi-conductors, are mostly homogeneous like water. Yet in contrast with the example of acequias, private firms control access to these resources. Therefore, as emphasized in Grossman, Helpman, and Lhuillier (2023), "the question for governments is not whether shortages adversely affect households but whether firms' private incentives to avoid such shortages fall short of (or exceed) what is socially desirable." To determine whether policy intervention is needed and how to make such policy efficient if justified, policymakers must first understand: why do private incentives distort investment in resilience? Answering this question will provide a way to test the efficiency of current policy. In particular, this paper asks: how does firms' use of homogeneous resources during shortages affect investment in resilience?

In some cases this private control creates a system with a similar purpose to that of acequias. Utility companies sell excess energy on utility markets. Hospitals coordinate use of scarce medical equipment like ventilators, surgical masks, or ambulances. These examples have large literatures that study how to make these markets efficient in order to maximize use of scarce resources during shortages. Why are these examples similar? Why are such secondary markets beneficial?

In other cases, such cooperation between firms does not occur. Cloud computing companies do not share computing resources with one another to cope with cyberattacks. Producers do not sell each other semi-conductors when they are in short supply. Why do secondary markets form in some cases and not others? How do private incentives affect whether secondary markets form and how efficiently they operate?

In this paper, I build on Grossman, Helpman, and Lhuillier (2023) to model an agent's decision to set a target capacity of a homogeneous good in anticipation of potential shortages of the good. At first I assume agents cannot exchange goods on a secondary market in order to establish the importance of such a market. I show that other homogeneous goods behave as does water in the example of acequias. Under the assumption of supply frictions during shortages and under uncertainty in shocks, goods will be misallocated between agents during shortages. As a result, the marginal value of the good will vary across agents. If an agent with a lower value for the good uses the good for themselves, this consumption creates a negative externality.

How will this misallocation of goods affect private investment in resilience? This investment in resilience could take many forms. For example, an automobile producer could diversify their supply chain to mitigate the effects of semi-conductor shortages. A cloud computing company could invest in better cybersecurity. An energy company could invest in more dependable energy sources. In my model, I abstract away from how producers invest in resilience. Instead I model agents' decision to invest in resilience as an option to pay a cost to increase the availability of the good under various shocks.

I show that if goods are not used efficiently during shortages, the market solution may either over or under invest in resilience. This is because the misallocation of goods during shortages creates two competing forces. On one hand, when compared to social optimum, the market solution will use an extra good inefficiently because during shortages, an extra good may not go to the agent who would get the most value from an extra good. Less efficient use of the marginal good, will push agents to under-invest in resilience. On the other hand, in the market solution, the goods allocated before this marginal good may also be misallocated. This will cause some agents to have a very high value for an extra good, pushing them to over-invest in resilience. If the agents are symmetric, I show that the convexity of the marginal value of a project determines wether the market solution over or under invests in resilience. This conclusion that depending on the projects' value functions, the market solution may either cause an over or under investment in resilience parallels a similar conclusion in Grossman, Helpman, and Lhuillier (2023), which shows that whether firms under or over invest in resilience depends on the elasticity of consumer demand.

A secondary market for the good could fix this misallocation during shortages. If during shortages, agents sold each other goods on a secondary market and the market clearing price was equal to the social planners' marginal value of the good, then the arising allocation would coincide with the social optimum. Private incentives, however, are likely to distort the secondary market. In the case of cloud computing, in the long term, companies could steal market share by letting their competitor fail to meet demand. In the example of firms using the good as an input to their production processes, giving inputs to competitors allows competitors to increase supply which weakens demand for the output of the first firm. On the other hand, the competitor will also be willing to pay a premium to take the input away from competition, so the effect on the secondary market will depend on consumer demand. In ongoing work, I fully develop this example which makes my model a direct extension of Grossman, Helpman, and Lhuillier (2023) to include homogeneous goods. Regardless of the form of private incentives, the relevant question is: under subsidies that achieve the social optimal allocation, if a secondary market were not feasible, how would private incentives affect the market price of the secondary market? I create a framework to understand such distortions. I show that in the specific example where agents are hoarders, the price on the secondary market is artificially high, so agents may be unwilling to pay to create a secondary market even if it is socially optimal.

How could policy intervention help foster an efficient secondary market? A common solution to this problem is a reserve, but to achieve the social optimum with only a reserve, agents would have to lower their targets so that they never receive more of the good than is socially optimal. Another common solution is a project based subsidy. In ongoing work, I show that a subsidy on transactions in the secondary market combined with a project based subsidy can decrease the total size of intervention. Another alternative is a policy which pays agents to enter into a smart contract requiring them to sell a predetermined number of goods for a given price depending on the state. All of these policies would be difficult to implement since the policymaker would need to know the social benefit of trading in different states in order to determine the size of the subsidy or the optimal smart contract. In ongoing work, I search for an incentive compatible mechanism to establish efficient secondary markets, which would make it optimal for agents to report the true values of their projects. In ongoing work, I also consider the impact of transaction costs in the secondary market. This will highlight the value of combining a subsidy with a reserve.

This paper builds on three strands of literature. The first strand focuses on supply chains. I build on the supply chain literature by showing a new effect of the rigidity of supply chain networks. As opposed to previous literature which focuses on how shocks propagate vertically in the supply chain, I consider how disruptions in the supply chain create an unharnessed value from relationships between firms at the same level of the supply chain. I also build on the novel policy analysis in Grossman, Helpman, and Lhuillier (2023). Another major contribution of Grossman, Helpman, and Lhuillier (2023) is modeling the nuances of homothetic demand beyond CES utility functions. I abstract away from these complexities of demand to make the problem more transferable to situations like governments investing in disaster relief resources and situations like cloud computing where consumers buy a subscription to a service that could be disrupted. Other supply chain literature focuses on forming relationships between producers and their suppliers. Grossman, Helpman, and Sabal (2023) considers the externalities in supply chains arising endogenously through sequential bargaining. Meanwhile Acemoglu and Tahbaz-Salehi (2021) focuses on amplification of shocks through a supply chain.

The second strand focuses on production networks. In this literature the prices of a firm's inputs adjust dynamically with shocks. As a result, the market price for inputs is efficient. I show that adding rigidities to production networks disrupts this power of flexible pricing and creates a misalignment in the value of inputs between firms. Acemoglu et al. (2012) shows how such networks transform idiosyncratic shocks into aggregate fluctuations. Liu and Tsyvinski (2024) studies production adjustment costs in input-output networks. Liu (2019) considers why these production networks create a need for industrial policy. Pellet and Tahbaz-Salehi (2023) introduces rigidities to production networks by modeling firms that must make their production decisions for some inputs under uncertainty. This leaves the possibility for heterogeneity in a firm's value for a given input. However, this paper focuses on the effects to the equilibrium and does not consider how firms could try to overcome this friction through a secondary market.

The third strand focuses on shortages. This literature spans many topics including energy markets, cloud computing resource sharing, hospital surge capacity, and interbank lending. I provide a common framework to unite a central problem in these literatures. The model provides an economic explanation for why cooperation between firms may be lower than what is socially optimal. The model also provides a way to test policy solutions to confront shortages, the principles of which can be applied to any of these industries. Of these literature on shortages, the work on interbank lending is the most expansive. Allen and Gale (2000) study how banks' can manage the risk of deposit outflows through interbank markets. Allen, Carletti, and Gale (2009) show the importance of a central bank to create sufficient liquidity in such markets. The central bank serves as a reserve for liquidity. In energy markets, Hogan (2013) proposes operating reserve to correct pricing distortions during shortages.

2 Model of Excess Capacity

Agents use a critical good to advance valuable projects. First each agent chooses a target quantity of the critical good under uncertainty in the value of the good and whether she will have access to the full quantity targeted. Next the state of the world is revealed to all agents. Finally, given the state of the world, each agent allocates her available quantity of the critical good between her projects to maximize their total value. For now I assume there are no secondary markets so agents cannot trade each other the critical good.

This decision under uncertainty can be interpreted as a supply friction that prevents the availability of the good to adjust to shocks. Private incentives come from the fact that agents only get value from some projects. As such, the social planner is an agent that gets value from all projects.

One way to interpret the model is a firm deciding how much excess inventory of inputs it would like to order from its suppliers. When taken in this context, my model follows a similar framework as Grossman, Helpman, and Lhuillier (2023) except I abstract the details of demand to give the problem applicability beyond the case of a producer. As shown in their paper, to understand firms incentives to invest in resilience a model must remove the distortions of market power. Their paper uses optimal subsidies to overcome the wedge between the market solution and the social optimum created by producer's market power. Instead, I assume the producer's value is equal to the social optimum. One micro-foundation for this assumption is that producers practice first-degree and consumers are only willing to buy one good. Alternatively, this assumption could be interpreted as only considering the problem after social planner has already implemented optimal project and state dependent consumption subsidies.

2.1 Model Setup

There is a discrete set of agents denoted I. There are a discrete set of projects denoted J. An agent $i \in I$ invests in a set of projects denoted $J_i \subseteq J$. I assume only one agent can invest in each project, so $\{J_i\}_{i \in I}$ partitions J. After the agents learn the state of the world $\omega \in \Omega$, which is realized with probability $f(\omega)$, agent i allocates her available units of the critical good, denoted

q_i, between the projects J_i. Denote q_{ij} as the amount of the critical good that agent i allocates to good j. So we have that:

$$\sum_{j \in J_i} q_{ij} \leq q_i$$

The value that the agent receives from the project depends on the quantity of the critical good that the agent allocates to the project, q_{ij}, and the state of the world, $\omega \in \Omega$. When deciding how to allocate the critical good between projects, the agent knows the state of the world; therefore, given a quantity of the critical good, q_i, agent i solves:

$$\begin{aligned} v_i(q_i, \omega) = \max_{\{q_{ij}\}_{j \in J_i}} & \sum_{j \in J_i} v_{ij}(q_{ij}, \omega) \\ \text{s.t.} & \sum_{j \in J_i} q_{ij} \leq q_i \end{aligned} \tag{1}$$

Where $v_i(q_i, \omega)$ denotes the total value of agent i and $v_{ij}(q_{ij}, \omega)$ denotes the value agent i receives from project j. Assume v_{ij} is strictly increasing and strictly concave, so the agents gain a decreasing marginal benefit from investing an additional unit of the critical good into project i.

Before the agent learns the state of the world, she must choose a target of how much critical good she wants; however, she might not receive as much of the good as she wanted. In particular, if agent i sets a target of θ_i units of the critical good, then she receives $q_i(\vec{\theta}, \omega)$ in state ω where $\vec{\theta} = \{\theta_i\}_{i \in I}$. I assume $q_i(\vec{\theta}, \omega)$ is weakly increasing in θ_i. Agents solve the following problem to prepare for potential crises:

$$V_i = \max_{\theta_i} V_i(\vec{\theta}) = \max_{\theta_i} \mathbb{E}[v_i(q_i(\theta_i))|\vec{\theta}_{-i}] - c_i(\theta_i) = \max_{\theta_i} \int_\Omega v_i(q_i(\vec{\theta}, \omega), \omega) f(\omega)\, d\omega \; - c_i(\theta_i)$$

Where $V_i(\vec{\theta})$ is the expected value of agent i given targets $\vec{\theta}$, where $\vec{\theta}_{-i} = \{\theta_l\}_{l \in I \setminus \{i\}}$ is the targets of other agents, and where $c_i(\theta_i)$ is the cost of setting the critical good target. Assume $c_i(\theta_i)$ is weakly convex in θ_i.

In the case of a producer selling differentiated goods that use a common input, then the critical good represents the common input and $v_i(q_{ij}, \omega)$ represents the profits from using q_{ij} units of inputs to produce final goods and selling those final goods at an implicit price. The equivalence between the producer's profit and the social welfare could arise from first-degree price discrimination where producers do not compete with one another or from optimal consumption subsidies. The critical good target represents the producer's order of an input. A supply disruption could cause the quantity of goods delivered to be lower than the producer's order.

2.1.1 Social Planner's Problem

The social planner is equivalent to an agent that gets value from all projects. In other words, if $J_i = J$, we get the social planner. Denote $v(q)$ as the value of the social planner given q units of the critical good. A delicate part of the social planner's problem is how to aggregate the cost and quantity functions. This aggregation does not necessarily benefit the social planner over the market solution in order to emphasize the real mechanism which is the inability of agents to adjust their supply to shocks. The full details of the social planner's problem can be found in Appendix Section (**??**).

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3 Conclusion

Although previous work has shown the importance of secondary markets during shortages, for example in interbank lending or electricity markets, I create a common framework to consider how such secondary markets could improve the use of scarce resources in other industrial settings. This model also gives a general answer to how inefficiency during crises affects preparation for crisis. I show that depending on the concavity of the marginal value of projects, agents may either over or under invest in crisis preparation. Furthermore, I consider how private incentives may prevent a secondary market from forming even if an efficient secondary market would be worth the cost of setting it up. Finally, the model provides a test for the general benefits and shortcomings of policies that invest in resilience. Although project based subsidies and reserves are the most common policy solutions to an under-investment in resilience, this investigation of secondary markets shows that subsidizing transactions on the secondary market could be a cheaper alternative.

In ongoing work, I consider the case of a producer in more depth by adding consumer demand as in Grossman, Helpman, and Lhuillier (2023). This will help determine under what assumptions about demand does the market solution under-invest or over-invest in resilience. It will also provide a micro-foundation for the distortions in the secondary market.

I will also expand the analysis to consider transaction costs on the secondary market. With transaction costs, private incentives will lead to an even greater misallocation in inputs because unlike the social planner, agents will not arrange their goods among one another to minimize the number of necessary transactions during shortages.

Finally I will continue to test this theory on the automobile industry by continuing work on Lewis-Hayre (2024). Empirical evidence from the auto industry suggests that profit maximization during shortages lowers access to new vehicles for lower-income consumers. The existence of a secondary market will only heighten this effect. Society's reliance on industrial products like electricity and computing power makes this question of inequality particularly important. As such, even in industrial settings, consideration of shortages should also capture the idea of necessity as is natural in the case of water. I plan to incorporate this question of access to resources during shortages using both theory and empirics.

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