**Problem-Based Learning Worksheet**

**Title:** Efficient Solutions to Traffic Congestion Externalities: More Complicated Than You Might Think

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**Objective:** Through this guided activity, students will gain a deeper understanding of congestion externalities by analyzing the welfare implications of road congestion and road tolls. Students will work in groups and report-out periodically so that the instructor can check understanding and guide learning.

**Brief Description:** This problem starts with a set of assumptions, which will ensure that unique answers exist. Then, there are five parts in this exercise that represent different scenarios (states of the world): 1) no congestion and no toll, 2) no congestion with a toll, 3) congestion and no toll, 4) congestion with a $9 toll; and 5) congestion with a $10 toll. Each scenario is depicted graphically, and students should derive answers from the graphs using letters for areas (rather than calculating areas). Students with more advanced economic training can compute the areas using calculus. Discussion questions are provided to help students understand the problems and analyze the outcomes of each scenario.

**Instructions:**

- Organize yourselves in groups of 3 or 4 students.
- Each person will be a scribe for 1-2 parts, and a single-sheet will be handed in by the group.
- When you are instructed to do so, complete the worksheet provided for each road scenario.
- Discussion questions for each section are provided on the back of each worksheet.

**Key assumptions:**

- The problem involves 18 potential car drivers with heterogeneous net private benefits (NPB) of driving on a particularly desirable road; think of a highway that gets drivers from point A to B quickly if there is no congestion. The NPB range between 2 and 19 (denominated in currency).
- NPB of driving reflects monetized utility from the trip minus the costs of taking the trip, including the opportunity costs of time.
- The only decision (choice) in this problem for the drivers is whether to enter the desirable road or not. If the driver does not enter, then they are assumed to pursue an outside option (their next best choice), and the NPB of that decision is assumed to be equal to zero, for simplicity.
- $x$ equals the total number of drivers who decide to enter the road.
- The only people in this society are assumed to be the drivers, and we assume that there are no pollution externalities associated with driving. Thus, social welfare measures simply aggregate the individual driver's welfare measures.

- For simplicity, a linear relationship is assumed for the aggregate NPB for the drivers. Any individual's NPB of driving equals the additional total social net benefit of driving when that person enters the road. That means that the aggregate marginal net benefit (MNB) is MNB = 20 – *x*. Although not essential, this problem is easiest to understand when one considers the drivers to be integer numbers: 1, 2, ..., 18.
- In some parts of the problem, congestion externalities will generate additional costs. The congestion cost for each driver is simplified to be a homogeneous cost of waiting (wasted time and car operation) that is an externality imposed on other users of the road.
- Congestion occurs in some scenarios when a road cannot handle the volume of drivers.
- When congestion occurs, congestion costs increase with the number of drivers, *x*. Each driver will bear this cost, which is termed the marginal private cost of congestion (MPCC). MPCC equals 0 if there are 8 drivers or fewer on the road. MPCC equals $0.5(x - 8)$ if there are more than 8 drivers. We can write this function as:

$$MPCC = \begin{cases} 0 & \text{if } 0 \leq x \leq 8 \\ 0.5(x - 8) & \text{if } x > 8 \end{cases}$$

- When more than 8 drivers enter the road they also generate external congestion costs on all of the other drivers. External congestion costs are added to MPCCs to determine the marginal social cost of congestion (MSCC), which is defined as

$$MSCC = \begin{cases} 0 & \text{if } 0 \leq x \leq 8 \\ x[0.5(x - 8)] & \text{if } x > 8 \end{cases}$$

- In some scenarios, drivers are charged a flat-rate toll to enter a road, and for simplicity this exercise assumes that it is costless to individuals and society to implement this toll. For instance, there is no toll booth that slows down the drivers.
- If tolls are used, then toll revenue will be collected. Assume that all toll revenue is costlessly transferred. This means that the toll revenue is not destroyed, and it is used to enhance the toll-revenue recipients' utility with the same marginal utility of money as those drivers who paid the toll.
- In each scenario, your task starts by determining how many drivers will enter the road. The number who enter the road will be assumed to follow a basic rule of maximizing NPB. As the decision to not enter is assumed to be worth zero, then each driver will enter the road when their assigned NPB is nonnegative, i.e., exceeds their own costs of congestion and tolls. In other words, drivers enter the road when NPB $\geq$ MPCC + toll.

**Preliminary Questions**

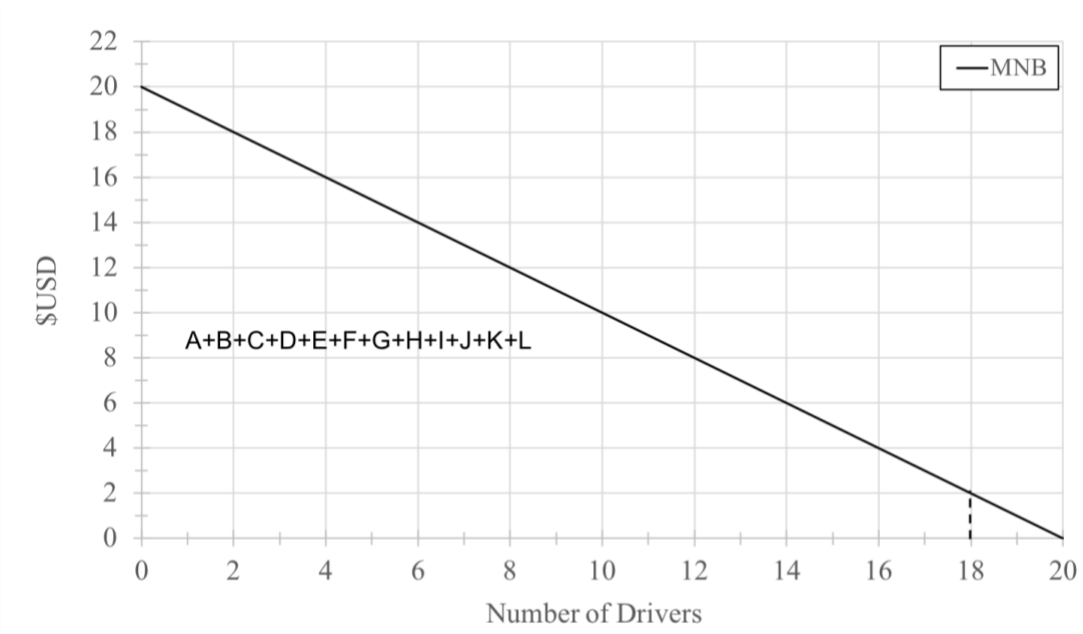
***Question:*** In one sentence, how would you define congestion? Discuss this among members of your group. *The definition of congestion in economics is a negative externality of consumption that is imposed on other users of the good.*[1] *How does this definition fit with your group's definition?*

***Question:*** Why might some drivers have higher NPB of driving than others?

[1] Weimer, D.L., and A.R. Vining. 2017. *Policy Analysis: Concepts and Practice*. Taylor & Francis.

**Problem-Based Learning Worksheet**

**Scenario 1** – Consider a road with no congestion and no tolls.




This graph might reflect the desirable road when the government has just completed the construction of new lanes.

Task: Use the graph above to answer the following questions.

| | **Scenario 1** (No Congestion / No Toll) |
|---|---|
| Assuming there are 18 potential drivers, how many of the drivers do you predict will enter the road? (use numbers) | |
| What is the social net benefit with this number of drivers? (use letters to represent areas of the graph)<br>Hint: Using different patterns to shade-in areas of benefits and costs will help you identify the net difference. | |
| What is the efficient toll in this scenario? (use numbers) | |
| What is the socially efficient number of drivers in this scenario? (use numbers) | |

## *STOP – wait for additional instructions*

The professor will now ask students to report out their answers. Prepare to answer the following discussion questions:

***Question:*** Why is ___ the efficient toll?
***Question:*** Why is ___ the efficient number of drivers?

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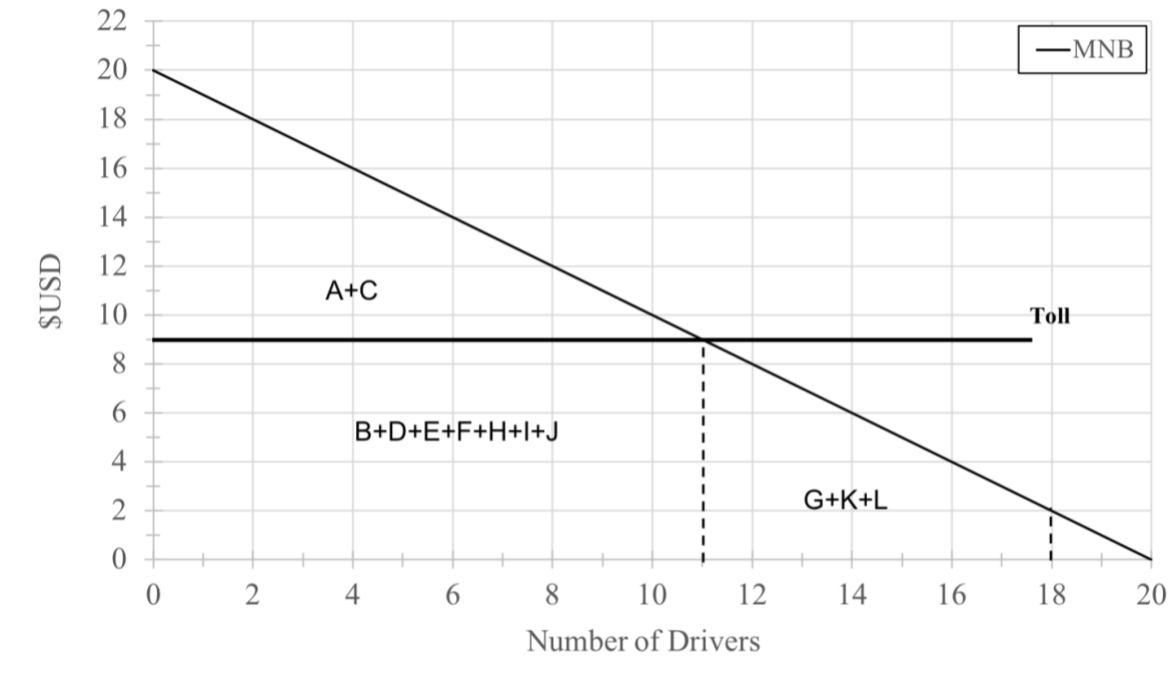
**Scenario 2** – Consider a road with no congestion and a $9 toll per vehicle.




This graph might reflect the desirable road when the government has just completed the construction of new lanes but also implements a toll.

Task: Use the graph above to answer the following questions.

| | **Scenario 2** (No Congestion / Toll) |
|---|---|
| Assuming there are 18 potential drivers, how many of the drivers do you predict will enter the road? (use numbers) | |
| What is the social net benefit with this number of drivers? (use letters to represent areas of the graph)<br>Hint: Using different patterns to shade-in areas of benefits and costs will help you identify the net difference. | |
| What is the efficient toll in this scenario? (use numbers) | |
| What is the socially efficient number of drivers in this scenario? (use numbers) | |

## *STOP – wait for additional instructions*

## Problem-Based Learning Worksheet

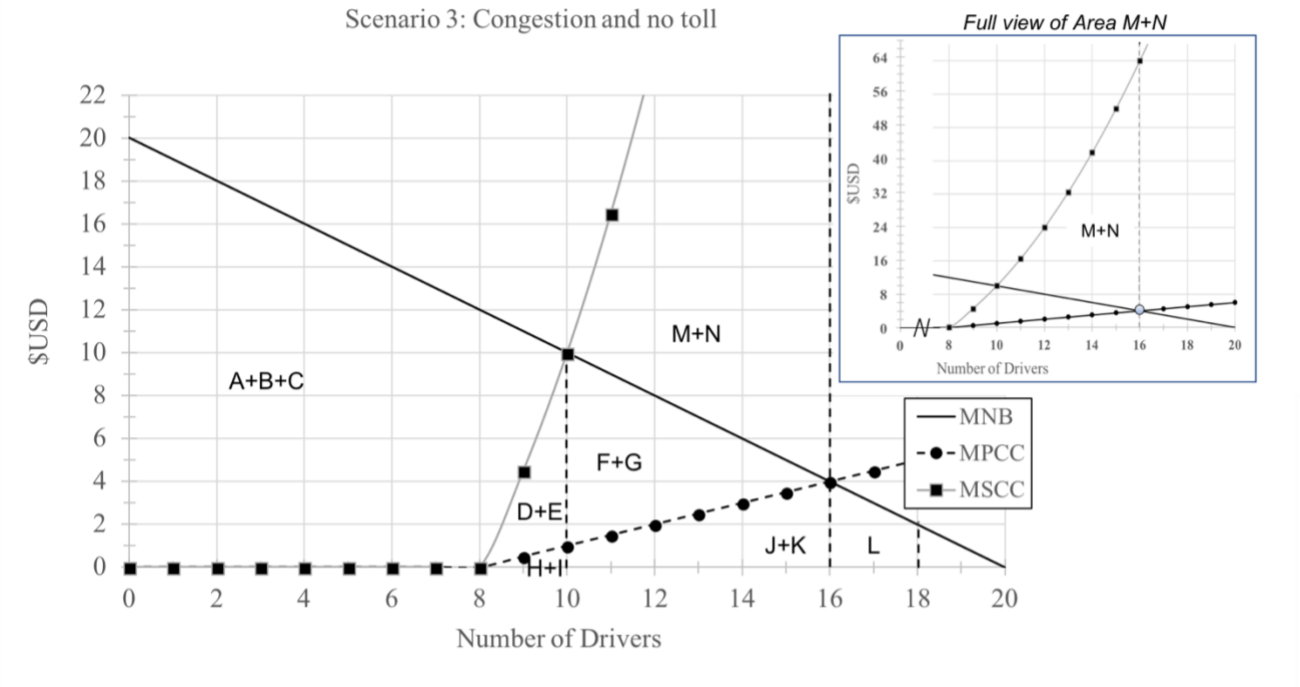
**Prepare answers for the following discussion questions:**

1. Who is excluded from using the road in this scenario?

2. Whose welfare changes the most? Briefly describe exactly how these drivers' lives would be changed from this policy? Is this policy used in the real world?

3. What area of the graph represents the efficiency loss generated by the toll?

**Scenario 3** – Consider a road with congestion and no toll.




<u>This graph might reflect the desirable road when the government has not added new lanes and uses no toll. This may also reflect a situation in which lanes are closed due to construction.</u>

Task: Use the graph above to answer the following questions.

| | **Scenario 3** (Congestion / No Toll) |
|---|---|
| Assuming there are 18 potential drivers, how many of the drivers do you predict will enter the road? (use numbers) | |
| What is the social net benefit with this number of drivers? (use letters to represent areas of the graph)<br>Hint: Using different patterns to shade-in areas of benefits and costs will help you identify the net difference. | |
| What is the efficient toll in this scenario? (use numbers) | |
| What is the socially efficient number of drivers in this scenario? (use numbers) | |

## *STOP – wait for additional instructions*

**Problem-Based Learning Worksheet**

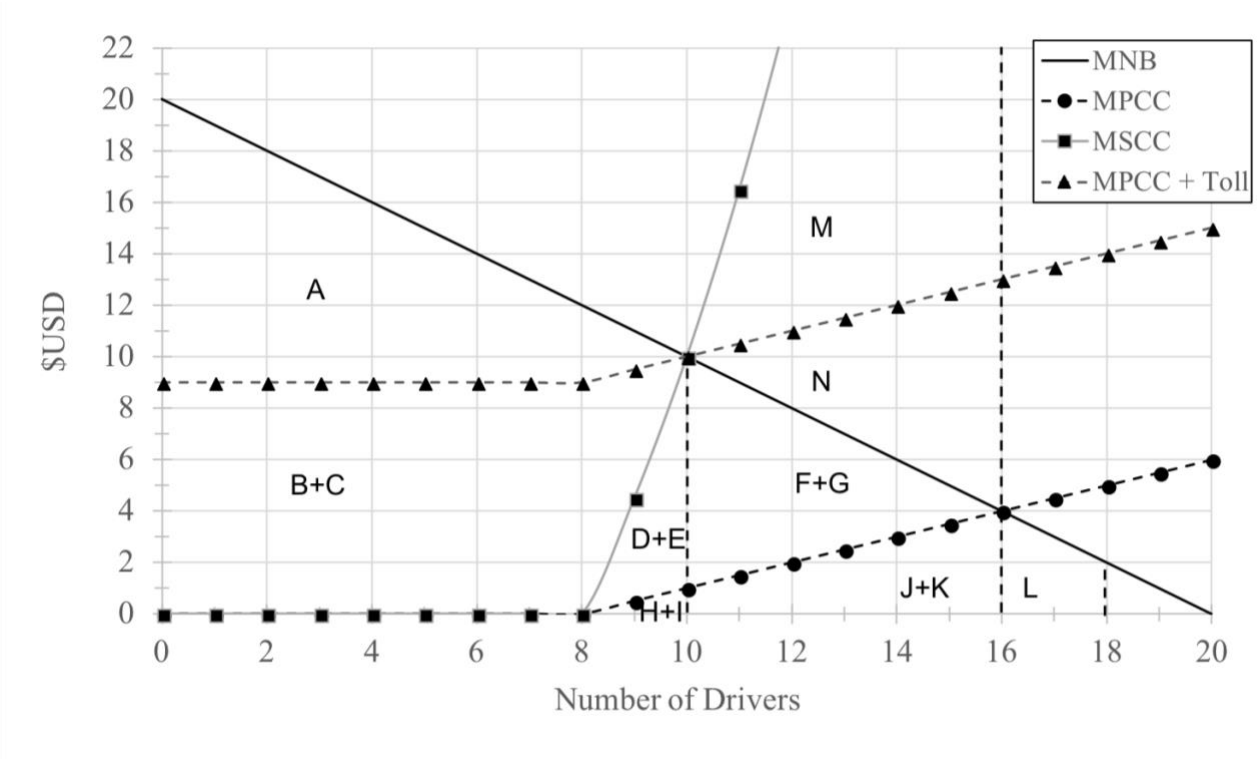
**Prepare answers for the following discussion questions:**

1. Why does the number of drivers exceed the socially efficient number of drivers?

2. Briefly describe the implications on social efficiency of this congestion (scenario 3 versus 1). Hint: What area equals the deadweight loss generated by the congestion externality?

3. Think about the dynamics of how people and businesses adjust to congestion. If the government builds more lanes, will this solve the problem of congestion (scenario 3 versus 1)?

**Scenario 4** – Consider a road with congestion and a $9 toll per vehicle.




This graph might reflect the desirable road when the government has not added new lanes and uses a $9 toll to address congestion.

Task: Use the graph above to answer the following questions.

| | **Scenario 4** (Congestion / Toll) |
|---|---|
| Assuming there are 18 potential drivers, how many of the drivers do you predict will enter the road? (use numbers) | |
| What is the social net benefit with this number of drivers? (use letters to represent areas of the graph)<br>Hint: Using different patterns to shade-in areas of benefits and costs will help you identify the net difference. | |
| What is the efficient toll in this scenario? (use numbers) | |
| What is the socially efficient number of drivers in this scenario? (use numbers) | |

## *STOP – wait for additional instructions*

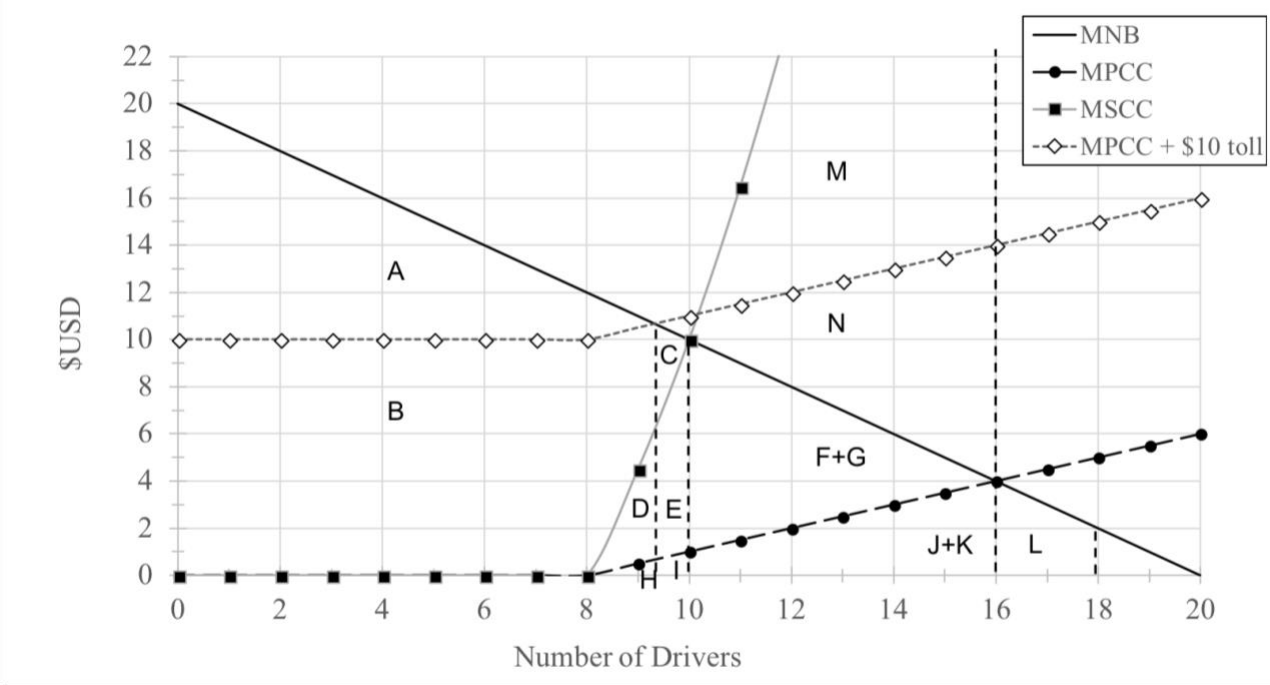
## Problem-Based Learning Worksheet

**Prepare answers for the following discussion questions:**

1. Briefly describe what changed from the perspective of drivers when the toll was added (scenario 4 versus 3)?

2. Briefly describe the implications on social efficiency of adding this new toll.
Hint: Identify the area of the graph that represents the avoided efficiency loss from congestion by implementing the toll.

**Scenario 5** – Consider a road with congestion and a $10 toll per vehicle.




This graph might reflect the desirable road when the government has not added new lanes and uses a $10 toll to address congestion.

Task: Use the graph above to answer the following questions.

| | **Scenario 5** (Congestion / $10 Toll) |
|---|---|
| Assuming there are 18 potential drivers, how many of the drivers do you predict will enter the road? (use numbers) | |
| What is the social net benefit with this number of drivers? (use letters to represent areas of the graph)<br>Hint: Using different patterns to shade-in areas of benefits and costs will help you identify the net difference. | |
| What is the efficient toll to correct for congestion externalities? (use numbers) | |

## *STOP – wait for additional instructions*

**Prepare answers for the following discussion questions:**

1. Why is the number of drivers less than the socially efficient number of drivers in Scenario 4?

2. Briefly describe the implications on social efficiency of increasing the toll from $9 to $10.
Hint: What area of the graph equals the deadweight loss generated by the excessive toll?

**Problem-Based Learning Worksheet**

**Summary and Discussion:**

Students can summarize answers from each scenario here for comparison

| | **Scenario** | | | | |
|---|---|---|---|---|---|
| ***Questions for all scenarios:*** | **1** (No congestion / No Toll) | **2** (No congestion / $9 Toll) | **3** (Congestion / No Toll) | **4** (Congestion / $9 Toll) | **5** (Congestion / $10 Toll) |
| How many drivers do you predict will enter the road? | | | | | |
| What is the social net benefit with this number of drivers? | | | | | |
| What is the efficient toll? | | | | | |
| What is the socially efficient number of drivers? | | | | | n/a |

**Additional discussion questions:**

1. How does the decision-making process in this activity differ from how individuals really make decisions about whether to drive or not?

2. Which drivers' lives are improved by the change from S3 to S4? Are any drivers made worse off by this policy? Describe in words what it means to be made better or worse off?

3. Is a flat-rate toll the optimal way to reduce road congestion?

4. What are the welfare implications of separate toll lanes that vehicles can enter for a fee?

5. What do you think would be done with the toll revenue? Would it be used for public transportation? Is there any possible fungability issue, i.e., would the government collecting the revenue just maintain previous levels of road budget, but instead redirect the savings from the tolls to projects that did not increase welfare?

6. What will happen to development patterns and road congestion in the future? Are tolls or road building better options for regions to manage congestion? If you said tolls are better, is there ever a point at which road building is better than very high tolls?