Results

Contents

Problem A

Direct Prompting

GPT-4o

Researcher:

> Problem: Consider an example in which a seller (she) owns a product which a buyer (he) is interested in obtaining. The seller has an option to make an investment in the product at cost of $3 to raise its value from $5 to $10 for the buyer. The investment is relationship specific, i.e. it only raises the value for this specific buyer. The investment is efficient (since 3 < 10 - 5), observable by the two parties, but unverifiable.
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> Assume Nash bargaining with equal bargaining power. Then, since 3 > 0.5*(10 - 5), the only renegotiation proof contract is the null contract.
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> Can the introduction of hard evidence solve this problem? Suppose a judge still cannot directly verify the investment, but it is commonly known that the buyer has a test for the good that yields a PASS result only if the investment was made and yields a FAIL result otherwise. The buyer cannot be forced to show these test results but may present them voluntarily if it is in his interest to do so. These test results can be verified as authentic by the judge. Is the null contract still the only renegotiation proof contract?

GPT 4-o:

In this scenario, the introduction of hard evidence in the form of a test that yields a PASS or FAIL result can indeed change the dynamics of the situation. Let's analyze how this affects the renegotiation-proof contract:

1. **Initial Situation**:

   - Without hard evidence, the seller's investment is not verifiable by a third party (e.g., a judge), and thus the only renegotiation-proof contract is the null contract. This is because the cost of investment ($3) is greater than the buyer's share of the surplus from the investment under Nash bargaining with equal power ($0.5 \times (10 - 5) = 2.5$).

2. **Introduction of Hard Evidence**:

   - With the test, the buyer can voluntarily present the test results to the judge. If the test yields a PASS, it serves as hard evidence that the seller made the investment.

   - The buyer has an incentive to present a PASS result if it leads to a better outcome for him, such as a higher surplus from the investment.

3. **Effect on Contracting**:

   - The availability of hard evidence changes the bargaining dynamics. If the buyer can credibly present a PASS result, the seller can be assured that the investment will be recognized, and thus she can expect to receive a fair share of the surplus.

   - This assurance can lead to a renegotiation-proof contract where the seller agrees to invest, knowing that the buyer will present the PASS result, allowing them to split the surplus efficiently.

4. **Conclusion**:

   - With the introduction of hard evidence, the null contract is no longer the only renegotiation-proof contract. The parties can agree on a contract that includes the investment, as the buyer's ability to present the test results ensures that the seller's investment will be recognized and compensated.

In summary, the introduction of hard evidence in the form of a verifiable test result allows for a renegotiation-proof contract that includes the investment, as it aligns the incentives of both parties and ensures that the seller's investment is acknowledged.

Claude 3.5 Sonnet

Researcher:

> Problem: Consider an example in which a seller (she) owns a product which a buyer (he) is interested in obtaining. The seller has an option to make an investment in the product at cost of $3 to raise its value from $5 to $10 for the buyer. The investment is relationship specific, i.e. it only raises the value for this specific buyer. The investment is efficient (since 3 < 10 - 5), observable by the two parties, but unverifiable.
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Claude 3.5 Sonnet:

Let me help analyze this hold-up problem with evidence.

Key Facts:

- Investment cost = $3

- Value without investment = $5

- Value with investment = $10

- Investment is efficient (benefit $5 > cost $3)

- Equal bargaining power (50-50 split of surplus)

- Test results: PASS if invested, FAIL if not invested

- Test results are voluntary but verifiable

Analysis:

1) First, let's confirm why the null contract fails without evidence:

- If seller invests $3, total surplus is $10 - $3 = $7

- With 50-50 split, seller gets $3.50 of surplus

- But seller bears full $3 cost

- Net payoff to seller = $3.50 - $3 = $0.50

- This is less than seller's payoff of $2.50 without investment (50% of $5)

- Therefore, seller won't invest

2) With evidence possibility:

- We can now write a contract that conditions payment on test results

- A possible contract:

  * Base price = $2.50 (50% of $5)

  * Additional payment of $4 if buyer shows PASS

  * No additional payment if buyer shows FAIL or nothing

3) Let's check incentives:

- If seller invests:

  * Buyer gets PASS result

  * Buyer will show PASS (gets $10 value, pays $6.50 total)

  * Buyer's net payoff = $3.50

* Seller gets $6.50 - $3 = $3.50

- If seller doesn't invest:
  * Buyer gets FAIL result
  * Buyer won't show result (would pay extra for no value)
  * Final price stays at $2.50
  * Buyer gets $5 - $2.50 = $2.50
  * Seller gets $2.50

4) This contract is renegotiation-proof:

- With investment: Neither party has incentive to renegotiate ($3.50 each)
- Without investment: Status quo gives $2.50 each, which is efficient for no-investment case

Therefore, the introduction of hard evidence (test results) can solve the hold-up problem. A contract that conditions additional payment on the presentation of a PASS result can achieve the efficient outcome and is renegotiation-proof. The null contract is no longer the only renegotiation-proof contract.

The key insight is that while the investment itself remains unverifiable, its effects become indirectly verifiable through the test results. The voluntary nature of showing the results works because the buyer has the right incentives to reveal good results and hide bad ones, which aligns with efficient investment.

OpenAI o1

Researcher:

> Problem: Consider an example in which a seller (she) owns a product which a buyer (he) is interested in obtaining. The seller has an option to make an investment in the product at cost of $3 to raise its value from $5 to $10 for the buyer. The investment is relationship specific, i.e. it only raises the value for this

specific buyer. The investment is efficient (since 3 < 10 - 5), observable by the two parties, but unverifiable.

Assume Nash bargaining with equal bargaining power. Then, since 3 > 0.5*(10 - 5), the only renegotiation proof contract is the null contract.

Can the introduction of hard evidence solve this problem? Suppose a judge still cannot directly verify the investment, but it is commonly known that the buyer has a test for the good that yields a PASS result only if the investment was made and yields a FAIL result otherwise. The buyer cannot be forced to show these test results but may present them voluntarily if it is in his interest to do so. These test results can be verified as authentic by the judge. Is the null contract still the only renegotiation proof contract?

OpenAI o1:

No, introducing this kind of test does not fundamentally change the hold-up problem in a way that would allow for a renegotiation-proof contract different from the null contract. The core issue is that the buyer, who stands to lose by revealing a PASS test (i.e., having to pay more), cannot be compelled to disclose it. Thus, the seller cannot credibly rely on that piece of “hard evidence” to enforce payment for her investment, because the buyer will simply withhold the test result if that outcome lowers his net payoff. Consequently, even with verifiable test results, there is no way to write a contract that guarantees the seller will be fully compensated for her relationship-specific investment, and the null contract remains the only renegotiation-proof outcome.

Auxiliary Test (OpenAI o1)

Researcher:

Consider an example in which a seller (she) owns a product which a buyer (he) is interested in obtaining. The seller has an option to make an investment in the product at cost of $3 to raise its value from $5 to $10 for the buyer. The investment is relationship specific, i.e. it only raises the value for this specific buyer. The investment is efficient (since 3 < 10 - 5), observable by the two parties, but unverifiable.

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Can the introduction of hard evidence solve this problem? Suppose a judge still cannot directly verify the investment, but it is commonly known that the buyer has a test for the good that yields a PASS result only if the investment was made and yields a FAIL result otherwise. The buyer cannot be forced to show these test results but may present them voluntarily if it is in his interest to do so. These test results can be verified as authentic by the judge. Is the null contract still the only renegotiation proof contract?

OpenAI o1:

Introducing this optional "hard evidence" does not change the underlying hold-up problem, so the null contract remains the only renegotiation-proof contract. The reason is that the buyer will disclose a PASS result only if it increases his overall surplus, and with equal bargaining power, revealing the higher value (10 rather than 5) typically leads to a higher price for him to pay. If revealing the result forces him to concede a larger share of the gain from investment, he will withhold it—negating the contract's ability to condition on the investment. Consequently, the investment remains effectively unverifiable for contractual purposes, preserving the hold-up problem and leaving the null contract as the sole renegotiation-proof option.

Researcher:

How about this:

New Proposed Contract:

- Buyer pays $8 upfront

- Seller must refund $5 if buyer shows FAIL test result

- No refund if no test is shown or if PASS test is shown

OpenAI o1:

Here is why this proposed contract can indeed induce efficient investment and remain renegotiation-proof:

1) Terms of the new contract:

• The buyer pays $8 upfront.

• If (and only if) the buyer presents a FAIL test result, the seller must refund $5 (so the seller nets $3).

• If the buyer shows PASS or shows nothing, there is no refund (so the seller nets $8).

2) Payoffs under each scenario:

– If the seller invests (cost $3) and thus produces a PASS test for the buyer, then there is no refund.

• Buyer's payoff = 10 (value of the good) − 8 (payment) = 2.

• Seller's payoff = 8 (received) − 3 (investment cost) = 5.

– If the seller does not invest (test FAIL):

• Buyer shows the FAIL result and gets a 5 refund, so the net price is 3. Buyer's payoff = 5 (value of the good) − 3 = 2.

• Seller's payoff = 3.

Because $5 > 3,$ the seller strictly prefers investing.

3) No incentive to renegotiate:

• After the seller invests, the buyer cannot fake a FAIL result, since the test is verifiable. Hence the buyer ends up paying 8.

• There is no beneficial renegotiation: once the system reveals PASS, the buyer is forced to stick to the no-refund condition.

• Both parties know the test cannot be falsified, so neither can credibly threaten to renegotiate for a different split.

Therefore, the seller invests, and this contract is not undermined by renegotiation. By conditioning a large refund on verifiable evidence of non-investment (FAIL) but no refund on PASS or no test, the contract aligns incentives and solves the hold-up problem. Hence it is indeed renegotiation-proof and achieves efficient investment.

LLM-LLM Student-Teacher Dialog

GPT-4o

GPT-4o as Teacher:

You are a student. You have to propose a solution to the problem given to you.

Consider an example in which a seller (she) owns a product which a buyer (he) is interested in obtaining. The seller has an option to make an investment in the product at cost of $3 to raise its value from $5 to $10 for the buyer. The investment is relationship specific, i.e. it only raises the value for this specific buyer. The investment is efficient (since 3 < 10 - 5), observable by the two parties, but unverifiable.

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Can the introduction of hard evidence solve this problem? Suppose a judge still cannot directly verify the investment, but it is commonly known that the buyer has a test for the good that yields a PASS result only if the investment was made and yields a FAIL result otherwise. The buyer cannot be forced to show these test results but may present them voluntarily if it is in his interest to do so. These test results can be verified as authentic by the judge. Is the null contract still the only renegotiation proof contract?

GPT-4o as Student:

In this scenario, the introduction of hard evidence in the form of a test that yields a PASS or FAIL result can indeed change the dynamics of the renegotiation proof contract. Let's analyze how this affects the situation:

1. **Initial Setup**:

- The seller can invest $3 to increase the product's value from $5 to $10 for the buyer.

- The investment is efficient because the cost ($3) is less than the increase in value ($10 - $5 = $5).

- Without any verifiable evidence, the only renegotiation proof contract is the null contract because the seller cannot credibly commit to making the investment.

2. **Introduction of Hard Evidence**:

- The buyer has a test that can verify if the investment was made (PASS) or not (FAIL).

- The buyer can choose to present the test results voluntarily if it benefits him.

3. **Impact on Bargaining**:

- If the seller makes the investment and the buyer presents a PASS result, the judge can verify this as authentic evidence.

- This changes the bargaining power because the seller can now credibly demonstrate that the investment was made, thus justifying a higher price.

- The buyer, knowing that he can verify the investment, has an incentive to negotiate a contract that reflects the higher value of the product.

4. **Renegotiation Proof Contract**:

- With the ability to present verifiable evidence, the buyer and seller can negotiate a contract that includes a clause for the buyer to present the test results.

- This contract can specify that if a PASS result is shown, the price reflects the higher value ($10), and if a FAIL result is shown, the price reflects the lower value ($5).

- This contract aligns incentives and is renegotiation proof because it ensures that both parties benefit from the investment being made and verified.

Therefore, with the introduction of hard evidence, the null contract is no longer the only renegotiation proof contract. The parties can now agree on a contract that incorporates the test results, allowing them to credibly commit to and verify the investment, thus facilitating efficient trade.

GPT-4o as Teacher:

Grade: PASS

Feedback:

The student's solution demonstrates a clear understanding of the problem and effectively analyzes how the introduction of hard evidence changes the dynamics of the renegotiation proof contract. Here are some key points that support the grade:

1. **Comprehension of Initial Setup**: The student correctly identifies the initial problem where the seller cannot credibly commit to making the investment due to the lack of verifiable evidence, resulting in the null contract being the only renegotiation proof contract.

2. **Introduction of Hard Evidence**: The student accurately describes the role of the test that yields a PASS or FAIL result, which can be presented by the buyer to verify the investment.

3. **Impact on Bargaining**: The student effectively explains how the ability to present verifiable evidence changes the bargaining power, allowing the seller to credibly demonstrate the investment and negotiate a higher price.

4. **Renegotiation Proof Contract**: The student proposes a contract structure that aligns incentives by incorporating the test results, ensuring that both parties benefit from the investment and facilitating efficient trade.

Overall, the student's solution is well-reasoned and demonstrates a thorough understanding of the problem and the implications of introducing hard evidence. The analysis is logical and supports the conclusion that the null contract is no longer the only renegotiation proof contract.

Claude 3.5 Sonnet

Claude 3.5 Sonnet as Teacher:

You are a student. You have to propose a solution to the problem given to you.

Problem: Consider an example in which a seller (she) owns a product which a buyer (he) is interested in obtaining. The seller has an option to make an investment in the product at cost of $3 to raise its value from $5 to $10 for the buyer. The investment is relationship specific, i.e. it only raises the value for this specific buyer. The investment is efficient (since 3 < 10 - 5), observable by the two parties, but unverifiable.

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Claude 3.5 Sonnet as Student:

Let me analyze this problem step by step as a student:

1) First, let's understand the initial situation:

- Without investment: Product value = $5
- With investment: Product value = $10
- Investment cost = $3
- Nash bargaining with equal power (50-50 split of surplus)
- Investment is efficient (benefit > cost)

2) The original problem without evidence:

- If investment is made, surplus = $10 - $5 = $5
- Each party gets half: $2.50
- Seller's net payoff = $2.50 - $3 = -$0.50
- Therefore, seller won't invest (hold-up problem)

3) Now with the test evidence:

- We can design a contract that uses this verifiable evidence
- Key insight: The buyer has incentive to show PASS if investment was made
- We can write a contract: "If test shows PASS, buyer pays additional amount"

4) Proposed Solution:

Let's design a contract with two components:

- Base price: $5 (value without investment)
- Contingent payment: +$4 if buyer shows PASS result

This works because:

- If seller invests:
  * Buyer gets value $10
  * Buyer will show PASS (gets $10 - $9 = $1)

* Seller gets $9 - $3 = $6

* Both parties better off than no investment

- If seller doesn't invest:

* Buyer gets value $5

* Buyer won't show test (would FAIL)

* Seller gets $5

* No incentive to deviate

Therefore, this contract is renegotiation-proof and solves the hold-up problem. The null contract is not the only solution when we have this form of hard evidence.

The key is that the verifiable test result allows us to condition payments on the investment, even though the investment itself isn't directly verifiable. This aligns incentives and enables efficient investment.

Claude 3.5 Sonnet as Teacher:

Let me evaluate this solution carefully.

Grade: PASS

Feedback:

The solution demonstrates a thorough understanding of the hold-up problem and how verifiable evidence can be used to create an efficient contract. Here are the key strengths:

1. Excellent analysis of the baseline scenario:

- Correctly identifies the initial hold-up problem

- Properly calculates the surplus split under Nash bargaining

- Shows why the seller won't invest without additional contractual protection

2. Strong understanding of the evidence mechanism:

- Recognizes that the test result, while voluntary, creates verifiable information

- Correctly notes that the buyer's incentives to reveal the test result can be used strategically

3. Well-designed contract solution:

- Base price ($5) + contingent payment ($4) structure is optimal

- Payment amounts create correct incentives for both parties

- Verifies that neither party has incentive to deviate

4. Complete verification of incentive compatibility:

- Shows payoffs for both investment and non-investment scenarios

- Demonstrates why the buyer will voluntarily reveal PASS results

- Proves the contract is renegotiation-proof

The solution correctly demonstrates that the null contract is not the only renegotiation-proof option when hard evidence is available. The proposed contract solves the hold-up problem by creating appropriate incentives for both efficient investment and truthful revelation of the test results.

One minor suggestion for improvement would be to explicitly mention that the $4 contingent payment was chosen to ensure the surplus split remains consistent with the Nash bargaining solution (though this is implicit in the numbers chosen).

Overall, this is an excellent analysis that shows deep understanding of contract theory and mechanism design.

OpenAI o1

OpenAI o1 as Teacher:

You are a student. You have to propose a solution to the problem given to you.

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OpenAI o1 as Student:

A concise way to see why voluntary disclosure of “PASS/FAIL” evidence does not solve the problem is as follows. Even though the test outcome is hard evidence, it is the buyer who controls whether to disclose that evidence. In equilibrium, he will only present the PASS result if doing so leaves him strictly better off. If a contract specified that a higher price must be paid upon a PASS outcome (indicating the seller’s costly investment), the buyer could simply choose not to disclose the PASS result (withholding the hard evidence) if the implied payment were too high. Hence, from the seller’s viewpoint, the evidence is useless as an enforcement tool unless it is disclosed mandatorily—and by assumption, it cannot be. Because of this, the contract still cannot effectively induce investment. Thus, the null contract remains the only renegotiation-proof contract.

OpenAI o1 as Teacher:

PASS. The student's reasoning correctly explains why voluntary disclosure of the test results does not fix the problem: since the buyer can simply withhold a "PASS" if it would trigger a higher payment, the contract cannot effectively reward the seller's investment. Hence, the null contract remains the only renegotiation-proof agreement.

LLM-Human Student-Teacher Dialog

GPT-4o

Researcher as Teacher:

You are a student. You have to propose a solution to the problem given to you.

Problem: Consider an example in which a seller (she) owns a product which a buyer (he) is interested in obtaining. The seller has an option to make an investment in the product at cost of $3 to raise its value from $5 to $10 for the buyer. The investment is relationship specific, i.e. it only raises the value for this specific buyer. The investment is efficient (since 3 < 10 - 5), observable by the two parties, but unverifiable.

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GPT 4-o as Student:

To address this problem, we need to analyze the impact of introducing hard evidence in the form of a test that the buyer can use to verify the seller's investment. The key points to consider are:

1. **Initial Situation**: Without the test, the investment is observable by both parties but unverifiable by a third party (e.g., a judge). This leads to a situation where the seller may not invest because the cost of investment ($3) is greater than the expected gain from bargaining ($0.5 \times (10 - 5) = 2.5$).

2. **Introduction of Hard Evidence**: With the test, the buyer can voluntarily present evidence that the investment was made. The test results are verifiable by the judge, which adds a layer of credibility to the buyer's claim.

3. **Incentives for the Buyer**: The buyer will present the test results if it is in his interest to do so. If the seller invests and the buyer can prove it, the buyer can negotiate a higher price for the product, reflecting the increased value of $10.

4. **Renegotiation Proof Contract**: The introduction of the test changes the dynamics. If the seller invests and the buyer presents the test results, the bargaining outcome will reflect the true value of the investment. The seller will receive a share of the surplus that justifies the investment cost.

5. **Conclusion**: With the ability to present verifiable evidence, the null contract is no longer the only renegotiation proof contract. The presence of the test allows for a contract where the seller invests, and the buyer presents evidence, leading to a bargaining outcome that compensates the seller for her investment.

In summary, the introduction of hard evidence in the form of a verifiable test result allows for a renegotiation proof contract that incentivizes the seller to invest, as it aligns the bargaining outcome with the efficient investment level.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: Please provide clear details of an actual contract including the prices for the trade in each relevant case.

GPT 4-o as Student:

To revise the solution, let's propose a specific contract that includes prices for the trade in each relevant case, taking into account the introduction of the test as hard evidence.

Proposed Contract:

1. **Contract Terms**:

- **Initial Agreement**: The seller agrees to invest $3 to increase the product's value from $5 to $10 for the buyer.

- **Price Without Investment**: If the seller does not invest, the price for the product remains at $5.

- **Price With Investment and Evidence**: If the seller invests and the buyer presents the test result showing a PASS, the price is set at $8.

2. **Rationale**:

   - **Without Investment**: The product's value remains at $5, and the price reflects this.

   - **With Investment and Evidence**: The product's value increases to $10. The price of $8 ensures that the seller recovers the investment cost ($3) and gains an additional $2, while the buyer benefits from a surplus of $2 (since $10 - $8 = $2).

3. **Incentives**:

   - The seller is incentivized to invest because the price of $8 covers the investment cost and provides a profit.

   - The buyer is incentivized to present the test results if the investment is made, as it allows him to obtain the product at a price that reflects the increased value.

4. **Renegotiation Proof**:

   - This contract is renegotiation proof because it aligns the interests of both parties with the efficient investment level. The seller is compensated for the investment, and the buyer benefits from the increased value.

By specifying these contract terms, we ensure that both parties have clear incentives to follow through with the investment and evidence presentation, leading to an efficient outcome.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: The investment is relationship specific. If the seller makes the investment, then in the mechanism you propose, the buyer can claim that the investment wasn't made alongside hiding the PASS result and bargain the price down to 7.5 under Nash bargaining.

GPT 4-o as Student:

To address the teacher's feedback, we need to ensure that the contract accounts for the possibility of the buyer hiding the PASS result and claiming that the investment wasn't made. Here's a revised solution:

Revised Contract:

1. **Contract Terms**:

   - **Initial Agreement**: The seller agrees to invest $3 to increase the product's value from $5 to $10 for the buyer.

   - **Price Without Investment**: If the seller does not invest, the price for the product remains at $5.

   - **Price With Investment and Evidence**: If the seller invests and the buyer presents the test result showing a PASS, the price is set at $8.

   - **Penalty for Hiding Evidence**: If the buyer does not present the test result and the seller claims the investment was made, the price is set at $7.5, and the buyer must pay an additional penalty of $1.5 to the seller.

2. **Rationale**:

   - **Without Investment**: The product's value remains at $5, and the price reflects this.

- **With Investment and Evidence**: The product's value increases to $10. The price of $8 ensures that the seller recovers the investment cost ($3) and gains an additional $2, while the buyer benefits from a surplus of $2.

- **Penalty for Hiding Evidence**: The penalty discourages the buyer from hiding the PASS result, as it would result in a higher total cost ($7.5 + $1.5 = $9) than simply presenting the evidence and paying $8.

3. **Incentives**:

- The seller is incentivized to invest because the price of $8 covers the investment cost and provides a profit.

- The buyer is incentivized to present the test results if the investment is made, as hiding the evidence would result in a higher cost due to the penalty.

4. **Renegotiation Proof**:

- This contract is renegotiation proof because it aligns the interests of both parties with the efficient investment level. The penalty mechanism ensures that the buyer cannot benefit from hiding evidence, thus maintaining the integrity of the contract.

By including a penalty for hiding evidence, we create a mechanism that discourages the buyer from misrepresenting the investment status, ensuring that the contract remains efficient and fair.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: When you say "If the buyer does not present the test result", it is not clear which test result you mean - PASS or FAIL?

GPT 4-o as Student:

To clarify the contract terms and address the teacher's feedback, let's specify the conditions related to the test results more clearly:

Revised Contract:

1. **Contract Terms**:

   - **Initial Agreement**: The seller agrees to invest $3 to increase the product's value from $5 to $10 for the buyer.

   - **Price Without Investment**: If the seller does not invest, the price for the product remains at $5.

   - **Price With Investment and PASS Result**: If the seller invests and the buyer presents the test result showing a PASS, the price is set at $8.

   - **Price With Investment and No Test Result**: If the seller claims the investment was made but the buyer does not present any test result (neither PASS nor FAIL), the price is set at $7.5, and the buyer must pay an additional penalty of $1.5 to the seller.

   - **Price With Investment and FAIL Result**: If the seller invests but the buyer presents a FAIL result, the price reverts to $5, as the investment is not verified.

2. **Rationale**:

   - **Without Investment**: The product's value remains at $5, and the price reflects this.

   - **With Investment and PASS Result**: The product's value increases to $10. The price of $8 ensures that the seller recovers the investment cost ($3) and gains an additional $2, while the buyer benefits from a surplus of $2.

- **With Investment and No Test Result**: The penalty discourages the buyer from withholding a PASS result, as it would result in a higher total cost ($7.5 + $1.5 = $9) than simply presenting the evidence and paying $8.

- **With Investment and FAIL Result**: If a FAIL result is presented, it indicates that the

investment was not successful or not made, justifying a price of $5.

3. **Incentives**:

- The seller is incentivized to invest because the price of $8 covers the investment cost and provides a profit.

- The buyer is incentivized to present the PASS test results if the investment is made, as hiding the evidence would result in a higher cost due to the penalty.

4. **Renegotiation Proof**:

- This contract is renegotiation proof because it aligns the interests of both parties with the efficient investment level. The penalty mechanism ensures that the buyer cannot benefit from hiding evidence, thus maintaining the integrity of the contract.

By specifying the conditions for each possible test result, we create a clear and enforceable contract that discourages the buyer from misrepresenting the investment status, ensuring that the contract remains efficient and fair.

Claude 3.5 Sonnet

Researcher as Teacher:

You are a student. You have to propose a solution to the problem given to you.

Problem: Consider an example in which a seller (she) owns a product which a buyer (he) is interested in obtaining. The seller has an option to make an investment in the product at cost of $3 to raise its value from $5 to $10 for the buyer. The investment is relationship specific, i.e. it only raises the value for this specific buyer. The investment is efficient (since 3 < 10 - 5), observable by the two parties, but unverifiable.

Assume Nash bargaining with equal bargaining power. Then, since 3 > 0.5*(10 - 5), the only renegotiation proof contract is the null contract.

Can the introduction of hard evidence solve this problem? Suppose a judge still cannot directly verify the investment, but it is commonly known that the buyer has a test for the good that yields a PASS result only if the investment was made and yields a FAIL result otherwise. The buyer cannot be forced to show these test results but may present them voluntarily if it is in his interest to do so. These test results can be verified as authentic by the judge. Is the null contract still the only renegotiation proof contract?

Claude 3.5 Sonnet as Student:

Let me analyze this problem step by step as a student:

1) First, let's understand the baseline scenario:

- Without investment: Product value = $5
- With investment: Product value = $10
- Investment cost = $3
- Equal bargaining power (50-50 split of surplus)

2) The original problem:

- Investment is efficient (benefit $5 > cost $3)
- But seller won't invest because she only gets 0.5*(10-5) = $2.5 of the surplus
- While bearing full cost of $3
- Hence, null contract is the only solution

3) New element: Hard evidence through testing
   - Test PASS = Investment made
   - Test FAIL = No investment
   - Buyer controls whether to show test results
   - Judge can verify test authenticity

4) Proposed Solution:

I believe we can design a better contract now. Here's my proposal:

- Initial contract terms:
  * Base price = $5 (value without investment)
  * Additional payment of $6 if buyer presents PASS test result
  * No additional payment if no test result or FAIL result

5) Why this works:
   - If seller invests ($3):
     * Buyer will show PASS test (gets $10 value, pays $11)
     * Seller gets $11 - $3 = $8
     * Buyer gets $10 - $11 = -$1
     * Total surplus = $7 (efficient)

   - If seller doesn't invest:
     * Buyer won't show test (gets $5 value, pays $5)
     * Seller gets $5
     * Buyer gets $5 - $5 = $0
     * Total surplus = $5

6) Conclusion:

This contract is renegotiation-proof because:

- Seller has incentive to invest ($8 > $5)

- Buyer has incentive to reveal PASS result when investment is made

- The contract achieves efficient investment

- Neither party has incentive to renegotiate

Therefore, the null contract is no longer the only renegotiation-proof contract when hard evidence is available.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: Given your contract design, the buyer has the incentive to not show the PASS result and get $10 of value for $5?

Claude 3.5 Sonnet as Student:

Let me revise my solution:

I apologize for my oversight. You're absolutely right - in my previous solution, if the seller invests:

- The buyer would get $10 value - $11 payment = -$1 if they show the PASS result

- The buyer would get $10 value - $5 payment = $5 if they don't show the PASS result

Therefore, the buyer would choose not to show the PASS result, making the seller unwilling to invest.

Here's my revised solution:

1) Proposed Contract Design:

- Base price = $5

- Additional payment of $4 if buyer presents PASS test result

- No additional payment if no test result or FAIL result

2) Let's verify the incentives:

If seller invests ($3):

- Buyer's options:

  * Show PASS: Gets $10 value - $9 payment = $1

  * Don't show PASS: Gets $10 value - $5 payment = $5

- Seller gets $5 payment - $3 investment = $2

If seller doesn't invest:

- Buyer's options:

  * Can't show PASS (test will show FAIL)

  * Gets $5 value - $5 payment = $0

- Seller gets $5 payment

3) I see this still doesn't work because:

- When seller invests, buyer still prefers not to show PASS ($5 > $1)
- Knowing this, seller won't invest as she gets $2 < $5

Let me try one more time:

Final Proposed Contract:

- Base price = $2
- Additional payment of $7 if buyer presents PASS test result
- No additional payment if no test result or FAIL result

Now let's verify:

If seller invests ($3):

- Buyer's options:
  * Show PASS: Gets $10 value - ($2 + $7) payment = $1
  * Don't show PASS: Gets $10 value - $2 payment = $8
- Seller gets $2 payment - $3 investment = -$1

If seller doesn't invest:

- Buyer gets $5 value - $2 payment = $3
- Seller gets $2 payment

I see that I still cannot solve this problem. The fundamental issue is that as long as the buyer controls whether to show the test result, they will always have the incentive to hide a PASS result to avoid the additional payment, and knowing this, the seller will never make the investment.

I need help understanding how to design a contract that makes both parties better off while ensuring the buyer will actually show the PASS result when the investment is made.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: I think you have shown that asking the buyer to show the PASS result and then pay a higher price does not work. Perhaps you should try an alternative approach?

Claude 3.5 Sonnet as Student:

Let me try a completely different approach:

New Proposed Contract:

- Buyer pays $8 upfront
- Seller must refund $5 if buyer shows FAIL test result
- No refund if no test is shown or if PASS test is shown

Let's analyze the incentives:

1) If seller invests ($3):

- Buyer gets PASS result and has no incentive to show it
  * Buyer's payoff: $10 value - $8 payment = $2
- Seller's payoff: $8 payment - $3 investment = $5

2) If seller doesn't invest:

- Buyer gets FAIL result and will show it
  * Buyer's payoff: $5 value - $8 payment + $5 refund = $2
- Seller's payoff: $8 payment - $5 refund = $3

This contract works because:

- Seller prefers to invest ($5 > $3)
- When seller invests, buyer has no reason to show test (keeps $2)
- When seller doesn't invest, buyer will show FAIL to get refund
- The threat of the buyer showing FAIL result disciplines the seller to invest

The contract is renegotiation-proof because:

- After investment, neither party wants to renegotiate
- Seller gets $5 (better than $3 without investment)
- Buyer gets $2 (same as what they would get if seller didn't invest)
- Total surplus of $7 is achieved (efficient outcome)

This solution works by flipping the incentive structure: instead of requiring the buyer to show PASS to trigger a payment, we require them to show FAIL to trigger a refund. This aligns the incentives correctly because the buyer will only show the test result when it benefits them (when seller doesn't invest), which in turn incentivizes the seller to invest.

OpenAI o1

Researcher as Teacher:

You are a student. You have to propose a solution to the problem given to you.

Problem: Consider an example in which a seller (she) owns a product which a buyer (he) is interested in obtaining. The seller has an option to make an investment in the product at cost of $3 to raise its value from $5 to $10 for the buyer. The investment is relationship specific, i.e. it only raises the value for this specific buyer. The investment is efficient (since 3 < 10 - 5), observable by the two parties, but unverifiable.

Assume Nash bargaining with equal bargaining power. Then, since 3 > 0.5*(10 - 5), the only renegotiation proof contract is the null contract.

Can the introduction of hard evidence solve this problem? Suppose a judge still cannot directly verify the investment, but it is commonly known that the buyer has a test for the good that yields a PASS result only if the investment was made and yields a FAIL result otherwise. The buyer cannot be forced to show these test results but may present them voluntarily if it is in his interest to do so. These test results can be verified as authentic by the judge. Is the null contract still the only renegotiation proof contract?

OpenAI o1 as Student:

A key point is that the buyer retains the discretion over whether to disclose the test result. If the buyer only presents the “PASS” result when it helps in bargaining (and withholds it otherwise), from the seller’s perspective this is no better than having no verifiable signal at all: the seller cannot compel the buyer to show the “PASS.”

Because $3 > 0.5 \times (10 - 5)$, no contract can be structured to guarantee ex ante that the seller’s investment cost of 3 will be recouped through bargaining—even if the investment's occurrence could be "proven" to a judge whenever the buyer chose to divulge the "PASS." As a result, the null contract continues to be the only renegotiation-proof contract under these conditions. The hold-up problem persists because the signal is not automatically disclosed and thus does not fully solve the verifiability issue required for an enforceable contract on the seller's investment.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: You have correctly identified that requiring revelation of the PASS result is not a feasible plan. Consider some alternative options?

OpenAI o1 as Student:

Here is a revised proposal that explores an alternative way to make the seller's investment verifiable—and thus ensure she can be paid if she makes it—without relying solely on the buyer's voluntary disclosure of "PASS."

One possibility is to shift the "default" outcome in the contract so that, unless the buyer provides (and verifies) a "PASS" test result, he must pay a higher price or face some other unfavorable default. Concretely, you can design a contingent-payment structure along these lines:

1. If the buyer provides authentic evidence of "PASS," then the contract price is set to an amount that compensates the seller for her $3 investment (for example, $9).

2. If the buyer provides a “FAIL” result or no test result at all, then the fallback price remains at (or near) $5.

Under this pay structure:

• If the seller invests (cost $3), she knows the good is actually worth $10 to the buyer; therefore, by making the investment, she triggers the possibility of a “PASS” result.

• The buyer, if he indeed obtains a “PASS,” prefers paying $9 for a $10-value product (net surplus $1) over paying $5 for a $5-value product (net surplus $0). Therefore, he is motivated to reveal the “PASS.”

• Given that the seller will receive $9 if she invests and the product’s value passes the test, her net payoff is $9 - $3 = $6, which is strictly higher than the $5 she gets if she does not invest. This motivates the seller to make the investment.

Written this way, the “threat” of reverting to a $5 price (and no surplus to the buyer) if the buyer withholds a “PASS” result effectively induces the buyer to disclose evidence in favor of higher value. The key step is to embed into the contract a default price or default payout that is worse for both parties, unless the high-value state is verifiably shown. That way, the buyer has an incentive to disclose, and the seller expects that disclosure will happen if she invests, solving the hold-up problem.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: Once the seller has invested, the product is now worth $10 to the buyer regardless of whether he presents the PASS result or not.

OpenAI o1 as Student:

Here is a revised proposal that directly addresses your teacher's point—namely, that once the seller invests, the product is worth $10 to the buyer whether or not he shows a test result.

The key is to shift the bargaining "default" so that the buyer has a real incentive to disclose evidence of investment (the PASS result). That means designing the price so that, in the absence of confirmed evidence that the investment took place, the buyer's payment is higher (e.g., $10), but if the buyer shows the PASS result, the payment is lowered to just enough to compensate the seller for the $3 cost.

Concretely, the contract can say:

• If the buyer produces verifiable "PASS," the buyer pays, say, $9.

• If the buyer does not or cannot produce the "PASS," the buyer must pay $10.

Why this works:

1. If the seller invests and the product is actually worth $10, the buyer gains $1 of surplus by disclosing (he pays $9 for a product worth $10), rather than forgoing disclosure and paying $10.

2. Knowing that the buyer will pay $9 if she invests (giving her net $9 − $3 = $6), the seller has an incentive to perform the $3 investment.

3. Conversely, if the seller does not invest, the buyer cannot produce a "PASS," so the fallback price remains $10 for a $5-value good, which is unattractive to both sides and leads them to renegotiate downward. No one prefers that path.

Because the buyer must actually show "PASS" to get the lower price, the otherwise moot test result becomes valuable to him. By making the default price higher, we switch the buyer’s payoff from “zero difference” to “strictly better off by disclosing PASS,” so that revealing the investment is in his self-interest.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: But, now the seller has no incentive to invest? If she does not invest, the buyer can only obtain a FAIL result, but now she gets a payment of $10 and a higher surplus than if she actually invests.

OpenAI o1 as Student:

Below is a revised approach that addresses the concern that, in the prior scheme, the seller might end up with a higher payoff by not investing (and thus producing a FAIL) than by investing (producing a PASS).

Key Idea: Make the seller strictly better off by investing, compared to not investing, through a carefully chosen “default” outcome if no PASS is shown.

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1) Specify in the contract that if the buyer produces a verifiable PASS (showing that the seller invested), then the buyer must pay a price high enough to compensate the seller for the $3 cost. For instance, the price could be $9.

• If the seller invests, her net payoff is 9 − 3 = \$6.

2) Specify that if the buyer fails to provide PASS (i.e., FAIL or no test), then the "default" is a low or even zero price—and no renegotiation that grants the seller any higher payoff.

• If the seller does not invest, she cannot produce PASS; hence, she ends up receiving \$0 (or something strictly less than \$6).

With these terms:

• If the seller invests, she earns \$6—and that is better than the fallback of (for example) \$0 if she does not invest.

• If the buyer sees that a PASS is possible, he will want to show it, because the good is worth \$10 to him, and paying \$9 is better than not trading at all (or trading at \$0 for zero value).

This structure avoids the problem of a large "fallback price" that makes the seller prefer not to invest. By setting a strictly lower payoff when the seller does not invest, the seller is incentivized to make the investment.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: But now the price obtained by the buyer is lower by hiding the PASS result again, so that he has no incentive to present it. Further, one cannot just ban negotiation. The idea is to try to design a mechanism to prevent renegotiation.

OpenAI o1 as Student:

Below is a revised approach that implements a “hostage” (deposit) mechanism so that neither side benefits from hiding the PASS result or renegotiating after the investment:

1) At the outset, require the buyer to post a deposit of D to an independent escrow (a third party).

2) If the seller makes the \$3 investment and, consequently, the seller’s product passes the buyer’s test (i.e., the buyer obtains PASS), then, upon the buyer’s public disclosure of PASS, the escrow returns most (or all) of D to the buyer but simultaneously pays an amount to the seller that covers (at least) her \$3 investment.

3) If the buyer fails to provide PASS, then the deposit is not refunded by the escrow—effectively forfeiting it to the seller, or awarding her a high enough payment that leaves the buyer worse off compared to disclosing PASS.

Why this avoids hiding PASS or renegotiation:

• Once the seller invests the \$3, the buyer surely gets a product worth \$10. Disclosing PASS lets him recover a large portion of D, so he strictly prefers to show the verifiable PASS result rather than hide it.

• Meanwhile, the seller sees that if she invests and obtains PASS, she will receive reimbursement (or surplus) through the escrow. By contrast, if she does not invest (no PASS), she cannot trigger that payout, so her payoff is lower.

• Because the deposit is held by a third party under fixed rules, there is no point in “renegotiating” for a cheaper price after the investment is made: the release of funds is tied to whether PASS is shown, not to a private bargain.

In short, this deposit mechanism aligns both sides’ incentives. The buyer wants to reveal PASS to reclaim his deposit, and the seller knows she will be paid for her relationship-specific investment, preventing the hold-up problem.

Problem B

Direct Prompting

GPT-4o

Researcher

Problem:

Policy: In country A, employers must pay a payroll tax of 31% on their workers' wages before 2007. From July 2007, this employer-paid payroll tax was reduced to 21% for workers aged 25 and under, while remaining at 31% for older workers. From January 2009, the payroll tax was further reduced to 15% for workers aged 26 and under, while remaining at 31% for older workers.

Data: (1) For each year from 2002-2013, we have administrative data on monthly wages (net of the employer payroll tax) that firms pay to each worker, along with worker characteristics including age. The wage measure is the full-time equivalent contracted monthly wage, adjusting for hours worked. (2) We also have matched employer-employee data showing the number of workers in each age group at each firm.

Key Empirical Facts:

After the reform, gross wages (wages + payroll tax) show a clear discontinuous drop at the age threshold

Net wages remain continuous across the age threshold

These patterns hold when following the same individual workers over time, for new hires only, and at all points in the wage distribution

Context: This is a developed western European economy with well-functioning capital markets and high ease of doing business

Automatic and immediate implementation of the tax cut through government payroll software used by all employers

Question: We want to study whether the reduction in employer payroll taxes for younger workers led to an increase in their wages (net of payroll tax). I plotted wages by age groups over time and found that while wages generally increase smoothly with age, this relationship remains smooth across the age threshold even after the reform. A difference-in-differences analysis comparing workers just above versus just below the age cutoff shows no significant effect on net wages. Why might this identification strategy fail to detect wage effects of the policy even if they existed?

GPT 4-o:

The identification strategy using a difference-in-differences (DiD) approach might fail to detect wage effects of the policy due to several potential reasons:

1. **Wage Stickiness**: Employers might not adjust net wages immediately in response to changes in payroll taxes due to wage stickiness. This could be due to long-term contracts, norms, or other frictions that prevent immediate wage adjustments.

2. **Pass-Through of Tax Cuts**: The reduction in payroll taxes may not have been fully passed through to workers in the form of higher net wages. Employers might have retained some of the tax savings, especially if they have bargaining power or if the labor market is not perfectly competitive.

3. **Measurement Error**: If there is any measurement error in the data, particularly in accurately capturing net wages or age, it could bias the results and obscure any true effects.

4. **Age Threshold Effects**: The discontinuity at the age threshold might not be sharp enough to capture the effects. If employers do not strictly adjust wages based on the age cutoff or if there are other confounding factors around the age threshold, it could dilute the estimated effect.

5. **Anticipation Effects**: If employers or workers anticipated the tax changes, they might have adjusted wages or employment practices before the policy change, leading to a smoothing of wages across the threshold.

6. **Heterogeneous Effects**: The policy might have heterogeneous effects that are not captured by the average treatment effect estimated by the DiD approach. For instance, the effect might vary by industry, firm size, or worker characteristics.

7. **Sample Size and Power**: If the sample size around the age threshold is small, the analysis might lack the statistical power to detect significant effects, even if they exist.

8. **External Factors**: Other concurrent economic changes or policies might have influenced wages during the study period, confounding the effect of the payroll tax reduction.

To address these issues, further robustness checks and alternative identification strategies, such as regression discontinuity design or instrumental variable approaches, could be explored to better isolate the causal impact of the payroll tax reduction on net wages.

Claude 3.5 Sonnet

Researcher:

Problem:

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Claude 3.5 Sonnet:

Let me analyze potential reasons why this identification strategy might fail to detect wage effects even if they existed. This is an important question in labor economics and tax incidence analysis.

Key Issues with the Identification Strategy:

1. Anticipation Effects and Dynamic Responses:

- Employers might adjust wages gradually over time rather than immediately at the policy implementation

- Firms may have anticipated the policy and adjusted wages before implementation

- The difference-in-differences might miss these temporal adjustments if they're spread out

2. Age-Based Selection Issues:

- Workers just above and below the age threshold may not be perfect comparisons

- There could be systematic differences in job types, skill levels, or career progression between age groups

- The age discontinuity might coincide with natural wage progression points in careers

3. Market-Wide General Equilibrium Effects:

- The policy could affect wages of both treated and control groups through labor market adjustments

- If younger and older workers are substitutes, the policy might affect wages of both groups

- This would violate the stable unit treatment value assumption (SUTVA)

4. Firm-Level Adjustment Mechanisms:

- Firms might adjust other margins besides wages (e.g., hours, benefits, training)

- The effects might be heterogeneous across firms based on their age composition

- Firms might redistribute the tax savings across all workers rather than just the affected group

5. Measurement and Implementation Issues:

- The full-time equivalent wage adjustment might not capture all forms of compensation

- The immediate implementation through payroll software might lead to mechanical adjustments that aren't captured in the wage measure

- There could be reporting or measurement issues around the age threshold

Better Identification Strategies Might Include:

1. Exploiting variation in firm exposure to the policy based on pre-reform age composition

2. Using longer-term outcomes to capture gradual adjustment

3. Examining other margins of adjustment besides wages

4. Comparing similar firms with different age compositions

5. Looking at new hires separately from incumbent workers

The key insight is that wage adjustments might occur through multiple channels and over different time horizons, making them difficult to detect with a simple difference-in-differences approach focused on the age threshold.

OpenAI o1

Researcher:

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OpenAI o1:

One main challenge here is that using an age-based cutoff (e.g., “under 25” vs. “over 25,” then “under 26” vs. “over 26”) creates a moving treatment group and a moving control group. Workers “just below” the age threshold eventually become “just above” it, so the same individuals move from treatment to control status over time. In this setup, the usual difference-in-differences (DiD) requirement—that treatment and control groups would have followed parallel trends in the absence of the policy—is often violated. Here are a few related factors that may cause the DiD to fail to detect wage effects, even if those effects exist:

1. Age-Slope Differences: Wages typically rise with age, and that rise can be quite steep for younger workers (due to accumulating experience, positions, etc.). A standard DiD approach (comparing "just below threshold" vs. "just above threshold") may not capture what wages would have looked like for the younger group had they remained untreated, because the older group's wage growth could differ systematically.

2. Moving Cutoff Cohorts: Individuals do not remain a fixed "under 25" or "under 26" forever; once they cross the age threshold, they are suddenly in the control group. As a result, the composition of the treatment group changes from one year to the next, making it difficult for a traditional DiD design to identify a clear "treated" vs. "untreated" comparison.

3. Anticipation and Selection: Employers and workers might adjust behavior in anticipation of workers aging out (or into) a lower payroll tax classification. For instance, firms might do very little wage adjustment after age 25 if they anticipate that the tax break will soon disappear anyway. This anticipation can dampen a purely data-driven DiD estimate of any net wage effect.

4. Offset in Other Dimensions: Even if the total labor-cost savings for younger workers does show up somewhere (e.g., better non-wage benefits, more training, or a small boost to gross wages that does not flow into higher net wages), the standard difference-in-differences approach focused on monthly net wages might miss it. If employers use the tax saving for something other than raising take-home pay, the DiD on net wages finds no impact.

5. Parallel Trends Assumption May Be Violated: The fundamental condition for a DiD approach is that, in the absence of the policy, treatment and control groups would have maintained parallel wage trends. In practice, age-group differences, career progression, and labor-market transitions can make these

trends diverge, especially since older cohorts do not serve as a perfect “no-policy” counterfactual for younger cohorts.

Hence, even if true underlying wage effects did exist—in the form of higher compensation for younger workers—this standard DiD strategy could easily fail to detect them due to the moving age threshold, systematic differences in wage growth across ages, and potential shifts in how compensation is delivered (gross wages vs. net wages vs. non-wage benefits).

Auxiliary Test (OpenAI o1)

Researcher:

Problem:

Policy: In country A, employers must pay a payroll tax of 31% on their workers' wages before 2007. From July 2007, this employer-paid payroll tax was reduced to 21% for workers aged 25 and under, while remaining at 31% for older workers. From January 2009, the payroll tax was further reduced to 15% for workers aged 26 and under, while remaining at 31% for older workers.

Data: (1) For each year from 2002-2013, we have administrative data on monthly wages (net of the employer payroll tax) that firms pay to each worker, along with worker characteristics including age. The wage measure is the full-time equivalent contracted monthly wage, adjusting for hours worked. (2) We also have matched employer-employee data showing the number of workers in each age group at each firm.

Key Empirical Facts:

After the reform, gross wages (wages + payroll tax) show a clear discontinuous drop at the age threshold

Net wages remain continuous across the age threshold

These patterns hold when following the same individual workers over time, for new hires only, and at all points in the wage distribution

Context: This is a developed western european economy with well-functioning capital markets and high ease of doing business

Automatic and immediate implementation of the tax cut through government payroll software used by all employers

Question: We want to study whether the reduction in employer payroll taxes for younger workers led to an increase in their wages (net of payroll tax). I plotted wages by age groups over time and found that while wages generally increase smoothly with age, this relationship remains smooth across the age threshold even after the reform. A difference-in-differences analysis comparing workers just above versus just below the age cutoff shows no significant effect on net wages. Why might this identification strategy fail to detect wage effects of the policy even if they existed?

Do you think this is a possible solution to the problem: Labor unions

OpenAI o1:

Labor unions (or other forms of collective wage setting) can certainly weaken or mask the pass-through of a payroll tax cut into net wages, making it harder for a difference-in-differences strategy to detect an effect. If, for example, wages are largely set by collective bargaining at the industry or firm level—rather than negotiated individually—then younger and older workers might be subject to almost identical wage agreements. In that setting, even a sizable payroll tax reduction for younger workers would not necessarily translate into clearly higher net wages for them relative to just-older counterparts. This lack of variation in effective wages across the age threshold would then be missed by a standard difference-in-differences approach, even if the policy in principle had the potential to boost net pay for younger workers.

LLM-LLM Student-Teacher Dialog

GPT-4o

GPT-4o as Teacher:

You are a student. You have to propose a solution to the problem given to you.

Problem:

Policy: In country A, employers must pay a payroll tax of 31% on their workers' wages before 2007. From July 2007, this employer-paid payroll tax was reduced to

21% for workers aged 25 and under, while remaining at 31% for older workers. From January 2009, the payroll tax was further reduced to 15% for workers aged 26 and under, while remaining at 31% for older workers.

Data: (1) For each year from 2002-2013, we have administrative data on monthly wages (net of the employer payroll tax) that firms pay to each worker, along with worker characteristics including age. The wage measure is the full-time equivalent contracted monthly wage, adjusting for hours worked. (2) We also have matched employer-employee data showing the number of workers in each age group at each firm.

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GPT-4o as Student:

The identification strategy using a difference-in-differences (DiD) approach might fail to detect wage effects of the policy due to several potential reasons:

1. **Wage Stickiness**: Employers might not adjust net wages immediately in response to changes in payroll taxes due to wage stickiness. Contracts, norms, or other frictions might prevent wages from adjusting quickly.

2. **Offsetting Adjustments**: Employers might offset the reduction in payroll taxes by adjusting other components of compensation, such as benefits or bonuses, rather than increasing net wages.

3. **Labor Market Segmentation**: The labor market might be segmented in such a way that younger workers are not perfect substitutes for older workers. This segmentation could lead to different wage-setting mechanisms that do not respond uniformly to payroll tax changes.

4. **Anticipation Effects**: If employers anticipated the policy change, they might have adjusted wages before the policy was implemented, leading to a smooth wage trend across the age threshold.

5. **Measurement Error**: There might be errors in measuring net wages or in accurately capturing the age of workers, which could obscure any effects of the policy.

6. **Policy Salience**: Employers might not be fully aware of the policy change or its implications, leading to a lack of response in wage adjustments.

7. **General Equilibrium Effects**: The policy might have broader effects on the labor market that are not captured by the DiD analysis, such as changes in labor demand or supply that affect wages across all age groups.

8. **Heterogeneous Effects**: The policy might have heterogeneous effects across different sectors or regions, which are not captured by the aggregate DiD analysis.

9. **Sample Selection**: The sample used for the DiD analysis might not be representative of the broader population, leading to biased estimates.

To address these issues, further analysis could involve exploring alternative identification strategies, such as regression discontinuity designs, or examining other outcomes like employment levels, hours worked, or firm-level responses. Additionally, qualitative data or surveys could provide insights into employer behavior and perceptions regarding the policy change.

GPT-4o as Teacher:

***Grade*: PASS**

***Feedback*:**

The student's solution provides a comprehensive analysis of potential reasons why the difference-in-differences (DiD) identification strategy might fail to detect wage effects of the payroll tax policy. The student has effectively identified several plausible explanations, demonstrating a good understanding of the complexities involved in empirical analysis of policy impacts. Here are some specific points of feedback:

1. **Wage Stickiness**: The student correctly identifies wage stickiness as a potential reason for the lack of immediate wage adjustments. This is a well-known phenomenon in labor economics and is relevant to the context.

2. **Offsetting Adjustments**: The suggestion that employers might adjust other components of compensation is insightful and highlights the multifaceted nature of compensation packages.

3. **Labor Market Segmentation**: Recognizing that younger and older workers might not be perfect substitutes is crucial for understanding differential impacts of the policy.

4. **Anticipation Effects**: The student correctly notes that anticipation effects could smooth wage trends, which is an important consideration in policy analysis.

5. **Measurement Error**: Identifying potential measurement errors shows attention to data quality, which is essential for robust empirical analysis.

6. **Policy Salience**: The mention of policy salience reflects an understanding of behavioral responses to policy changes, which can vary based on awareness and understanding.

7. **General Equilibrium Effects**: The student acknowledges broader labor market effects, which is important for a comprehensive analysis.

8. **Heterogeneous Effects**: Recognizing potential heterogeneity in policy effects across sectors or regions adds depth to the analysis.

9. **Sample Selection**: The student correctly points out that sample selection could bias estimates, which is a critical consideration in empirical research.

Overall, the student's solution is well-reasoned and covers a wide range of potential issues that could affect the identification strategy. The suggestion to explore alternative identification strategies and examine other outcomes is appropriate and demonstrates a proactive approach to addressing the limitations of the current analysis.

Claude 3.5 Sonnet

Claude 3.5 Sonnet as Teacher:

You are a student. You have to propose a solution to the problem given to you.

Problem:

Policy: In country A, employers must pay a payroll tax of 31% on their workers' wages before 2007. From July 2007, this employer-paid payroll tax was reduced to 21% for workers aged 25 and under, while remaining at 31% for older workers. From January 2009, the payroll tax was further reduced to 15% for workers aged 26 and under, while remaining at 31% for older workers.

Data: (1) For each year from 2002-2013, we have administrative data on monthly wages (net of the employer payroll tax) that firms pay to each worker, along with worker characteristics including age. The wage measure is the full-time equivalent contracted monthly wage, adjusting for hours worked. (2) We also have matched employer-employee data showing the number of workers in each age group at each firm.

Key Empirical Facts:

After the reform, gross wages (wages + payroll tax) show a clear discontinuous drop at the age threshold

Net wages remain continuous across the age threshold

These patterns hold when following the same individual workers over time, for new hires only, and at all points in the wage distribution

Context: This is a developed western European economy with well-functioning capital markets and high ease of doing business.

Automatic and immediate implementation of the tax cut through government payroll software used by all employers.

Question: We want to study whether the reduction in employer payroll taxes for younger workers led to an increase in their wages (net of payroll tax). I plotted wages by age groups over time and found that while wages generally increase smoothly with age, this relationship remains smooth across the age threshold even after the reform. A difference-in-differences analysis comparing workers just above versus just below the age cutoff shows no significant effect on net wages. Why might this identification strategy fail to detect wage effects of the policy even if they existed?

Claude 3.5 Sonnet as Student:

As a student, I'll analyze potential reasons why the identification strategy might fail to detect wage effects even if they existed. Here's my proposed solution:

1. Spillover Effects:

- The difference-in-differences strategy assumes that the treatment and control groups are independent

- Workers just above and below the age threshold likely work in similar positions within the same firms

- Firms might adjust wages of both groups similarly to maintain internal pay equity and prevent workplace tensions

- This violates the Stable Unit Treatment Value Assumption (SUTVA)

2. Anticipation Effects:

- The policy changes were announced in advance

- Firms might have adjusted wages gradually before the implementation

- This would violate the parallel trends assumption

- The sharp discontinuity analysis might miss these gradual adjustments

3. Labor Market Dynamics:

- Young workers (treatment group) typically experience faster wage growth than slightly older workers

- This underlying difference in wage trajectories could mask the policy effect

- The control group might not provide a valid counterfactual for wage growth

4. Firm-level Adjustments:

- Firms might respond to the tax cut by:
  * Adjusting their hiring patterns
  * Changing job assignments
  * Modifying workplace responsibilities
- These changes could affect both age groups, diluting the measured effect

5. Market Structure:

- Given the context of a developed economy with well-functioning markets
- Firms might compete for workers across age groups
- This competition could lead to wage equilibration across the threshold
- The local comparison might miss broader market adjustments

Recommendation for Better Identification:

- Use firm-level variation in exposure to the policy
- Compare firms with different age compositions before the reform
- Exploit variation in local labor market conditions
- Consider longer-term effects beyond the immediate threshold

This analysis suggests that while the policy might have had wage effects, the local age-threshold comparison might be too narrow to capture the full impact due to market adjustments and spillovers.

Claude 3.5 Sonnet as Teacher:

Let me evaluate this solution based on my knowledge of grading criteria and economic analysis.

Grade: PASS

Feedback:

Strengths:

1. The solution demonstrates excellent understanding of identification challenges in labor economics, particularly regarding:

- SUTVA violations through spillover effects
- Anticipation effects and their impact on parallel trends
- Labor market dynamics specific to age groups
- Firm-level strategic responses

2. The analysis appropriately leverages the context provided:

- Considers the developed economy setting
- Acknowledges the role of well-functioning capital markets
- Takes into account the automatic implementation through payroll software

3. The solution shows sophisticated understanding of:

- Internal labor market dynamics
- Wage-setting mechanisms within firms
- Market equilibrium effects

4. The recommendations for better identification are well-reasoned and feasible given the available data mentioned in the problem (matched employer-employee data and administrative wage data).

Areas for Enhancement (though not requiring revision):

1. Could have mentioned potential heterogeneous effects across the wage distribution, since the data allows for this analysis

2. Might have explored more deeply how the immediate implementation through payroll software affects the identification strategy

3. Could have discussed potential differential effects across firm sizes or industries

The solution passes because it:

1. Uses only the data explicitly mentioned as available

2. Provides a comprehensive analysis of identification challenges

3. Suggests feasible alternative approaches using the available data

4. Demonstrates understanding of both technical econometric issues and practical labor market mechanisms

5. Correctly interprets the institutional context and its implications

The analysis is particularly strong in recognizing that local age-threshold comparisons might miss broader equilibrium effects, which is crucial in labor market analysis.

OpenAI o1

OpenAI o1 as Teacher:

You are a student. You have to propose a solution to the problem given to you.

Problem:

Policy: In country A, employers must pay a payroll tax of 31% on their workers' wages before 2007. From July 2007, this employer-paid payroll tax was reduced to 21% for workers aged 25 and under, while remaining at 31% for older workers. From January 2009, the payroll tax was further reduced to 15% for workers aged 26 and under, while remaining at 31% for older workers.

Data: (1) For each year from 2002-2013, we have administrative data on monthly wages (net of the employer payroll tax) that firms pay to each worker, along with worker characteristics including age. The wage measure is the full-time equivalent contracted monthly wage, adjusting for hours worked. (2) We also have matched employer-employee data showing the number of workers in each age group at each firm.

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Context: This is a developed western European economy with well-functioning capital markets and high ease of doing business.

Automatic and immediate implementation of the tax cut through government payroll software used by all employers.

Question: We want to study whether the reduction in employer payroll taxes for younger workers led to an increase in their wages (net of payroll tax). I plotted wages by age groups over time and found that while wages generally increase smoothly with age, this relationship remains smooth across the age threshold even after the reform. A difference-in-differences analysis comparing workers just above versus just below the age cutoff shows no significant effect on net wages. Why might this identification strategy fail to detect wage effects of the policy even if they existed?

OpenAI o1 as Student:

> One key reason is that a simple difference-in-differences strategy based on age thresholds may fail to provide a valid counterfactual for the “no-policy” world. Put differently, workers just above and just below the cutoff could differ

in ways that are not accounted for when you compare them—especially if the underlying wage-growth patterns or worker characteristics vary with age in a smooth but non-linear way. Some specific issues include:

1. Age-Related Career Progression or Selection:

Even within narrow age bands, older workers may have acquired slightly more experience, changed firms, or negotiated contracts differently from younger workers. If these differing wage-growth trajectories or selection patterns are not properly controlled for, a difference-in-differences design using just-above vs. just-below ages as treatment vs. control could mask any true effect of the tax policy.

2. Anticipation or Timing of the Policy:

Employers (and workers) might anticipate that younger workers lose eligibility once they cross the threshold and adjust wages or hiring decisions accordingly, well before they switch from “subsidized” to “non-subsidized” status. This anticipation can blur any immediate post-threshold differences in wages within a short window around the cutoff.

3. General versus Local Effects:

The reform may have had an overall effect on younger workers’ wages, but it might not show up precisely at the age cutoff. For instance, if the policy affects wage-bargaining power for all workers under 26 (or if the pass-through happens slowly or only for workers with certain types of contracts), a narrow age-band difference-in-differences might miss those dynamics.

4. Offset by Other Factors:

Even if employers do pass on some of the tax cut to net wages, other economic forces (e.g., seniority-based pay schedules, firm-level wage agreements) might offset or mask the pass-through near the cutoff. The policy effect could be diffused across all younger workers, leaving only a small difference between those 25 (or 26) and 26 (27) in ways that are hard to detect statistically.

In short, if younger and older cohorts (just around the threshold) do not form a clean control-and-treatment group, or if the timing and local comparisons do not capture how wage setting actually unfolds, then the difference-in-differences estimate will not reveal the policy's underlying effect on net wages—even if the policy really did shift them for younger workers.

OpenAI o1 as Teacher:

PASS

Feedback:

Your explanation clearly outlines why a simple difference-in-differences design may fail to capture the true effect of the payroll tax reduction on net wages when treatment is defined narrowly around age thresholds. You identify plausible reasons—such as age-related progression, anticipatory behavior by firms and workers, broader effects not limited to the local cutoff, and offsetting institutional factors—that can confound a comparison of workers just above vs. just below the cutoff. These points all provide solid rationales for why a naïve differences approach might obscure an actual wage response. To strengthen your analysis, you might also emphasize the importance of modeling pre-existing trends and considering functional form differences in wage growth by age. Overall, the solution is sound and points to key limitations in identification when using narrow age-band comparisons.

LLM-Human Student-Teacher Dialog

GPT-4o

Researcher as Teacher:

You are a student. You have to propose a solution to the problem given to you.

Problem:

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GPT 4-o as Student:

The identification strategy using a difference-in-differences (DiD) approach might fail to detect wage effects of the policy for several reasons:

1. **Wage Stickiness**: Wages, especially net wages, tend to be sticky due to contracts, norms, or institutional factors. Even if the payroll tax reduction lowers the cost of employing younger workers, firms might not immediately adjust net wages due to these frictions.

2. **Pass-Through of Tax Cuts**: The reduction in payroll taxes might not be fully passed through to workers in the form of higher net wages. Employers might retain some or all of the tax savings, especially if they have bargaining power or if the labor market is not perfectly competitive.

3. **Substitution Effects**: Employers might respond to the tax cut by hiring more younger workers instead of increasing their wages. This could lead to an increase in employment for younger workers without a corresponding increase in their net wages.

4. **General Equilibrium Effects**: The policy change might have broader effects on the labor market that offset the expected wage increase. For example, if the supply of younger workers increases in response to the tax cut, this could put downward pressure on wages.

5. **Measurement Error**: If there are errors in measuring net wages or if the data does not accurately capture all components of compensation (e.g., bonuses, benefits), this could obscure the effects of the policy.

6. **Age Threshold Effects**: The discontinuity at the age threshold might not be sharp enough to detect differences in net wages, especially if there is a smooth transition in other factors affecting wages around the age cutoff.

7. **Heterogeneous Treatment Effects**: The effect of the payroll tax reduction might vary across different groups of younger workers (e.g., by industry, firm

size, or worker skill level), and these heterogeneous effects might not be captured by the DiD analysis.

8. **Time Lag in Effects**: The impact of the tax cut on net wages might take time to materialize, and the analysis period might not be long enough to capture these delayed effects.

To address these issues, further analysis could involve exploring alternative identification strategies, such as regression discontinuity designs, or examining other outcomes like employment levels or firm profitability. Additionally, qualitative data or case studies could provide insights into how firms and workers perceive and respond to the tax changes.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: The paper's empirical work rules out these standard economic mechanisms. The effects are immediate and stable, hold for new hires, show up clearly in gross wages, and appear across the wage distribution.

GPT 4-o as Student:

Given the feedback that standard economic mechanisms have been ruled out and that effects are immediate and stable, we need to consider alternative explanations for why the difference-in-differences (DiD) analysis might not detect changes in net wages despite clear effects on gross wages. Here are some revised considerations:

1. **Tax Incidence and Bargaining Power**: The incidence of the payroll tax cut might fall more on employers than on employees due to bargaining dynamics. If employers have significant bargaining power, they might retain the benefits of the tax cut, leading to unchanged net wages for workers despite reductions in gross wages.

2. **Compensation Structures**: Firms might adjust other components of compensation instead of net wages. For example, they might increase non-wage benefits, bonuses, or invest in training for younger workers, which would not be captured in net wage measures.

3. **Labor Market Segmentation**: The labor market might be segmented in a way that the tax cut affects different segments differently. For instance, younger workers in high-demand sectors might see wage increases, while those in low-demand sectors do not, averaging out to no significant effect in the aggregate data.

4. **Policy Anticipation and Adjustment**: Firms might have anticipated the policy change and adjusted their wage structures in advance, leading to immediate effects on gross wages but no observable change in net wages post-reform.

5. **Data Limitations**: There might be limitations in the data used for the DiD analysis, such as missing variables that capture other relevant factors affecting net wages, or issues with the granularity of the data that obscure wage changes.

6. **Behavioral Responses**: Workers might respond to the tax cut in ways that offset potential net wage increases, such as reducing hours worked or shifting to part-time positions, which could affect the observed net wage outcomes.

To address these points, further analysis could involve examining detailed compensation data, exploring sector-specific effects, or using qualitative methods to understand firm and worker responses to the policy change. Additionally, considering alternative econometric approaches or robustness checks could help clarify the observed patterns in net wages.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: The paper's empirical work also rules out these explanations. The effects are clear in gross wages, immediate and stable, hold across sectors and the wage distribution, and appear for new hires. The data is comprehensive administrative data on wages.

GPT 4-o as Student:

Given the feedback that the empirical work rules out the previous explanations and that the data is comprehensive, we need to explore other potential reasons for the lack of observed effects on net wages despite clear effects on gross wages. Here are some revised considerations:

1. **Regulatory or Institutional Constraints**: There may be regulatory or institutional constraints that prevent firms from adjusting net wages even when gross wages change. For example, collective bargaining agreements or minimum wage laws might limit the ability of firms to alter net wages in response to payroll tax changes.

2. **Perception and Expectations**: Workers and employers might perceive the payroll tax cut as temporary or uncertain, leading them to maintain existing wage structures rather than adjusting net wages. This could be due to expectations about future policy reversals or economic conditions.

3. **Focus on Gross Wages**: Firms might focus on adjusting gross wages as a signal to attract or retain workers, especially if gross wages are more visible or salient to workers than net wages. This could lead to changes in gross wages without corresponding changes in net wages.

4. **Behavioral Factors**: Behavioral factors might play a role in how firms and workers respond to the tax cut. For instance, firms might prioritize maintaining stable net wages to avoid potential dissatisfaction or turnover among workers.

5. **Policy Implementation and Compliance**: There might be issues related to the implementation or compliance with the payroll tax policy that affect how net wages are adjusted. For example, firms might face administrative challenges in recalculating net wages, leading to delays or inconsistencies in wage adjustments.

To further investigate these possibilities, additional qualitative research could be conducted to understand firm and worker perceptions and behaviors related to the policy change. Moreover, exploring the role of institutional factors and examining case studies of specific firms or sectors could provide deeper insights into the observed wage patterns.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: The data shows firms did receive real cost savings from the tax cut (visible in gross wages), so the key question is: what Regulatory or Institutional Constraints might prevent them from passing these savings specifically to young workers?

GPT 4-o as Student:

Given the feedback, we need to focus on identifying specific regulatory or institutional constraints that might prevent firms from passing on the cost savings from the payroll tax cut to young workers in the form of higher net wages. Here are some potential constraints to consider:

1. **Collective Bargaining Agreements**: If young workers are covered by collective bargaining agreements, these agreements might set wage floors or standardize wages across age groups, limiting the ability of firms to adjust net wages specifically for younger workers.

2. **Minimum Wage Laws**: In some cases, minimum wage laws might set a binding floor for net wages, preventing firms from adjusting wages downward for older workers to offset increases for younger workers, thereby maintaining wage parity across age groups.

3. **Internal Wage Policies**: Firms might have internal wage policies or equity considerations that aim to maintain consistent wage structures across different age groups to avoid perceptions of unfairness or discrimination among employees.

4. **Labor Market Regulations**: Regulations related to equal pay or age discrimination might discourage firms from differentiating net wages based on age, even if the payroll tax cut applies specifically to younger workers.

5. **Administrative Complexity**: The complexity of adjusting payroll systems to reflect different tax rates for different age groups might lead firms to maintain existing wage structures to avoid administrative burdens or errors.

6. **Union Influence**: In sectors with strong union presence, unions might negotiate to ensure that cost savings from tax cuts are distributed across all workers, rather than being concentrated among younger workers.

To further explore these constraints, it would be beneficial to examine the specific regulatory and institutional context of the country in question, including labor laws, union agreements, and firm-level wage policies. Additionally, conducting interviews or surveys with employers and industry representatives could provide insights into how these constraints influence wage-setting practices.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: The explanation based on collective bargaining within the union sounds promising. If you wanted to use the DiD method to verify this explanation, how would you design the DiD treatment?

To reiterate, we have the following Data: (1) For each year from 2002-2013, we have administrative data on monthly wages (net of the employer payroll tax) that firms pay to each worker, along with worker characteristics including age. The wage measure is the full-time equivalent contracted monthly wage, adjusting for hours worked. (2) We also have matched employer-employee data showing the number of workers in each age group at each firm.

GPT 4-o as Student:

To verify the explanation based on collective bargaining within unions using the difference-in-differences (DiD) method, we can design a treatment that compares the wage outcomes of workers in unionized firms versus non-unionized firms before and after the payroll tax cut. Here's how the DiD design could be structured:

1. **Treatment and Control Groups**:

   - **Treatment Group**: Young workers (aged 26 and under) in unionized firms. These workers are subject to collective bargaining agreements, which might constrain wage adjustments.

   - **Control Group**: Young workers (aged 26 and under) in non-unionized firms. These workers are not subject to collective bargaining agreements, so firms might have more flexibility to adjust wages.

2. **Pre-Treatment and Post-Treatment Periods**:

   - **Pre-Treatment Period**: Before the payroll tax cut (e.g., 2002-2006).

   - **Post-Treatment Period**: After the payroll tax cut (e.g., 2007-2013).

3. **Outcome Variable**:

   - The outcome variable is the net wage (after employer payroll tax) for young workers.

4. **DiD Estimation**:

   - Estimate the DiD model to compare the changes in net wages for young workers in unionized firms versus non-unionized firms before and after the tax cut. The key parameter of interest is the interaction term between the post-treatment period and the treatment group, which captures the differential effect of the tax cut on net wages in unionized firms.

5. **Additional Considerations**:

- Control for other worker characteristics (e.g., age, education, experience) and firm characteristics (e.g., industry, size) that might affect wage outcomes.

- Conduct robustness checks to ensure that the results are not driven by other factors or trends.

By comparing the wage changes in unionized versus non-unionized firms, this DiD design can help identify whether collective bargaining agreements in unionized firms are a constraint on passing payroll tax savings to young workers. If the DiD estimate shows a smaller or no increase in net wages for young workers in unionized firms compared to non-unionized firms, it would support the hypothesis that collective bargaining limits wage adjustments.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: This is not a good approach, since this country has near universal union coverage (~90%).

GPT 4-o as Student:

Given the high level of union coverage in the country, using union versus non-union firms as the basis for the DiD design is not feasible. Instead, we need to consider other dimensions along which firms might differ in their ability or willingness to pass on payroll tax savings to young workers. Here's a revised approach:

1. **Treatment and Control Groups**:

   - **Treatment Group**: Young workers (aged 26 and under) in firms where collective bargaining agreements are more likely to constrain wage adjustments. This could include firms in industries with particularly strong or rigid collective bargaining agreements.

   - **Control Group**: Young workers (aged 26 and under) in firms where collective bargaining agreements are less likely to constrain wage adjustments. This could include firms in industries with more flexible or decentralized bargaining structures.

2. **Pre-Treatment and Post-Treatment Periods**:

   - **Pre-Treatment Period**: Before the payroll tax cut (e.g., 2002-2006).

   - **Post-Treatment Period**: After the payroll tax cut (e.g., 2007-2013).

3. **Outcome Variable**:

   - The outcome variable is the net wage (after employer payroll tax) for young workers.

4. **DiD Estimation**:

   - Estimate the DiD model to compare the changes in net wages for young workers in firms with more rigid versus more flexible collective bargaining agreements before and after the tax cut. The key parameter of interest is the interaction term between the post-treatment period and the treatment group, which captures the differential effect of the tax cut on net wages in firms with more rigid agreements.

5. **Additional Considerations**:

   - Control for other worker characteristics (e.g., age, education, experience) and firm characteristics (e.g., industry, size) that might affect wage outcomes.

   - Conduct robustness checks to ensure that the results are not driven by other factors or trends.

By focusing on differences in the rigidity of collective bargaining agreements across industries or firm types, this DiD design can help identify whether these agreements are a constraint on passing payroll tax savings to young workers. If the DiD estimate shows a smaller or no increase in net wages for young workers in firms with more rigid agreements compared to those with more flexible agreements, it would support the hypothesis that collective bargaining limits wage adjustments.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: I do not have such data. This strategy is infeasible. Consider other ways in which the policy might affect different groups of firms less or more so we can exploit that variation to identify.

GPT 4-o as Student:

Given the constraints and feedback, we need to consider other dimensions along which firms might be differentially affected by the payroll tax policy. Here’s a revised approach focusing on firm characteristics that might influence their response to the policy:

1. **Treatment and Control Groups**:

   - **Treatment Group**: Young workers (aged 26 and under) in smaller firms. Smaller firms might have less financial flexibility or different wage-setting practices compared to larger firms, potentially affecting their ability to pass on tax savings.

   - **Control Group**: Young workers (aged 26 and under) in larger firms. Larger firms might have more resources and established wage structures, possibly leading to different responses to the tax cut.

2. **Pre-Treatment and Post-Treatment Periods**:

   - **Pre-Treatment Period**: Before the payroll tax cut (e.g., 2002-2006).

   - **Post-Treatment Period**: After the payroll tax cut (e.g., 2007-2013).

3. **Outcome Variable**:

   - The outcome variable is the net wage (after employer payroll tax) for young workers.

4. **DiD Estimation**:

   - Estimate the DiD model to compare the changes in net wages for young workers in smaller versus larger firms before and after the tax cut. The key parameter of interest is the interaction term between the post-treatment period and the treatment group, which captures the differential effect of the tax cut on net wages in smaller firms.

5. **Additional Considerations**:

   - Control for other worker characteristics (e.g., age, education, experience) and firm characteristics (e.g., industry) that might affect wage outcomes.

   - Conduct robustness checks to ensure that the results are not driven by other factors or trends.

By focusing on firm size as a dimension of variation, this DiD design can help identify whether smaller firms, which might face different constraints or incentives, are less able or willing to pass payroll tax savings to young workers. If the DiD estimate shows a smaller or no increase in net wages for young workers in smaller firms compared to larger firms, it would suggest that firm size and associated characteristics influence the ability to adjust wages in response to the policy.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: There is no reason to believe that firm size would affect the ability to pass through tax savings.

GPT 4-o as Student:

Given the feedback, let's consider another approach that might reveal differential impacts of the policy across firms. We need to identify characteristics that could logically influence a firm's ability or decision to pass on payroll tax savings to young workers. Here's a revised approach:

1. **Treatment and Control Groups**:

- **Treatment Group**: Young workers (aged 26 and under) in firms with a high proportion of young workers. Firms with a larger share of young workers might be more sensitive to the payroll tax cut, as it affects a significant portion of their workforce.

- **Control Group**: Young workers (aged 26 and under) in firms with a low proportion of young workers. These firms might be less affected by the tax cut, as fewer of their employees benefit from it.

2. **Pre-Treatment and Post-Treatment Periods**:

   - **Pre-Treatment Period**: Before the payroll tax cut (e.g., 2002-2006).

   - **Post-Treatment Period**: After the payroll tax cut (e.g., 2007-2013).

3. **Outcome Variable**:

   - The outcome variable is the net wage (after employer payroll tax) for young workers.

4. **DiD Estimation**:

   - Estimate the DiD model to compare the changes in net wages for young workers in firms with a high versus low proportion of young workers before and after the tax cut. The key parameter of interest is the interaction term between the post-treatment period and the treatment group, which captures the differential effect of the tax cut on net wages in firms with a high proportion of young workers.

5. **Additional Considerations**:

   - Control for other worker characteristics (e.g., age, education, experience) and firm characteristics (e.g., industry) that might affect wage outcomes.

   - Conduct robustness checks to ensure that the results are not driven by other factors or trends.

By focusing on the proportion of young workers within firms, this DiD design can help identify whether firms with a larger share of young employees are more likely to pass on payroll tax savings in the form of higher net wages. If the DiD estimate shows a greater increase in net wages for young workers in firms with a high proportion of young workers compared to those with a low proportion, it would suggest that the concentration of young workers influences the firm's response to the policy.

Claude 3.5 Sonnet

Researcher as Teacher:

You are a student. You have to propose a solution to the problem given to you.

Problem:

Policy: In country A, employers must pay a payroll tax of 31% on their workers' wages before 2007. From July 2007, this employer-paid payroll tax was reduced to 21% for workers aged 25 and under, while remaining at 31% for older workers. From January 2009, the payroll tax was further reduced to 15% for workers aged 26 and under, while remaining at 31% for older workers.

Data: (1) For each year from 2002-2013, we have administrative data on monthly wages (net of the employer payroll tax) that firms pay to each worker, along with worker characteristics including age. The wage measure is the full-time equivalent contracted monthly wage, adjusting for hours worked. (2) We also have matched employer-employee data showing the number of workers in each age group at each firm.

Key Empirical Facts:

After the reform, gross wages (wages + payroll tax) show a clear discontinuous drop at the age threshold.

Net wages remain continuous across the age threshold.

These patterns hold when following the same individual workers over time, for new hires only, and at all points in the wage distribution.

Context: This is a developed western European economy with well-functioning capital markets and high ease of doing business

Automatic and immediate implementation of the tax cut through government payroll software used by all employers.

Question: We want to study whether the reduction in employer payroll taxes for younger workers led to an increase in their wages (net of payroll tax). I plotted wages by age groups over time and found that while wages generally increase smoothly with age, this relationship remains smooth across the age threshold even after the reform. A difference-in-differences analysis comparing workers just above versus just below the age cutoff shows no significant effect on net wages. Why might this identification strategy fail to detect wage effects of the policy even if they existed?

Claude 3.5 Sonnet as Student:

As a student, I'll analyze potential reasons why the identification strategy might fail to detect wage effects even if they existed. Here's my proposed solution:

1. Spillover Effects:

- The difference-in-differences strategy assumes that the treatment and control groups are independent

- Workers just above and below the age threshold likely work in similar positions within the same firms

- Employers might adjust wages of both groups similarly to maintain internal pay equity and prevent workplace tensions

- This violates the Stable Unit Treatment Value Assumption (SUTVA)

2. Anticipation Effects:

- Since the policy changes were announced in advance, firms might have adjusted their wage-setting behavior before implementation

- This could lead to:

  * Pre-reform wage adjustments

  * Changes in hiring patterns

  * Strategic timing of promotions or raises

- The pre-treatment period might not be a clean "control" period

3. Dynamic Labor Market Adjustments:

- The age threshold creates incentives for firms to:
  * Adjust their workforce composition
  * Modify job descriptions
  * Restructure positions
- These adjustments might take time to manifest
- Short-term analysis might miss longer-term wage effects

4. Market-Wide Equilibrium Effects:
- The policy affects all firms simultaneously
- Labor market equilibrium might adjust through:
  * Changes in job creation
  * Modification of job requirements
  * Shifts in skill demands
- These market-wide changes could affect both treatment and control groups

5. Measurement Issues:
- The full-time equivalent wage measure might not capture:
  * Changes in hours worked
  * Non-wage compensation
  * Job quality differences
- The reform might affect these unmeasured dimensions

6. Selection Effects:
- The policy might influence:
  * Which workers are hired
  * Who stays in their jobs
  * Career progression patterns

- This could create composition changes that mask wage effects

Alternative Approach Suggestion:

To better identify wage effects, I would suggest:

1. Using firms with different exposure to young workers pre-reform
2. Exploiting variation in local labor market conditions
3. Analyzing longer-term outcomes
4. Including measures of non-wage compensation
5. Examining firm-level outcomes like profitability and employment composition

This approach would help address the limitations of the current identification strategy and provide a more comprehensive understanding of the policy's effects.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: Your response focuses on potential methodological problems with the difference-in-differences design. However, the paper's empirical work rules out most of these explanations:

The patterns persist when following individual workers over time, ruling out selection and composition effects.

The effects are immediate and stable, ruling out dynamic adjustment issues.

The wage measure is comprehensive and the implementation was clean, ruling out measurement issues.

The results hold for new hires and across the wage distribution, ruling out anticipation effects.

Claude 3.5 Sonnet as Student:

Thank you for the feedback. I'll revise my solution focusing on more fundamental economic explanations given that methodological issues have been ruled out by the empirical evidence.

Revised Solution:

The identification strategy might fail to detect wage effects due to fundamental features of the labor market:

1. Tax-Benefit Linkage:

- Workers might view payroll taxes as linked to future benefits (e.g., pensions, unemployment insurance)

- If younger workers perceive the tax cut as reducing their future benefits

- They might demand higher gross wages to compensate

- This could offset the tax reduction effect on net wages

2. Wage Rigidity and Institutional Constraints:

- Collective bargaining agreements might set standardized wages across age groups

- These agreements typically:

  * Have multi-year durations

  * Include automatic progression scales

   * Apply uniformly across age groups

- Making it difficult for wages to adjust differently for different age groups

- Even if firms want to adjust wages, institutional constraints prevent it

3. Efficiency Wage Considerations:

- Firms might pay above-market wages to:

   * Maintain worker motivation

   * Reduce turnover

   * Ensure high-quality work

- These efficiency wage levels might be determined by factors independent of tax rates

- Making wages sticky even when tax costs change

4. Market Power in Wage Setting:

- If employers have significant wage-setting power (monopsony)

- They might:

   * Keep the tax savings as increased profits

   * Have little incentive to raise wages

   * Face limited competitive pressure to pass tax savings to workers

- Especially if workers have limited mobility or bargaining power

5. Implicit Contracts:

- Firms and workers might operate under implicit long-term contracts

- These contracts often:

   * Smooth wages over time

   * Include career progression paths

   * Maintain relative pay structures

- Making it costly to adjust wages differently for different age groups

- Even when tax costs change

This revised explanation focuses on structural features of the labor market that could prevent tax incidence from shifting to wages, even when the empirical methodology is sound and implementation is clean. These explanations are consistent with the comprehensive empirical evidence presented in the paper, including the persistence of effects across individual workers over time, immediate implementation, and consistency across the wage distribution.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: Tax-benefit linkage cannot explain the results since the reform did not reduce any benefits.

Efficiency wage considerations would predict differential effects for young workers

Monopsony power alone would not explain the lack of differential effects at the age threshold.

Implicit contracts cannot explain the results since the patterns hold even for new hires.

The data shows that firms did receive real cost savings from the tax cut, so the key question is: what institutional feature might prevent them from passing these savings specifically to young workers?

Claude 3.5 Sonnet as Student:

Thank you for the feedback. I'll revise my solution to focus specifically on institutional features that could prevent firms from passing tax savings to young workers, even when they realize cost savings.

Revised Solution:

The key institutional feature that might prevent firms from passing tax savings specifically to young workers is wage fairness norms and their enforcement through both formal and informal mechanisms:

1. Equal Pay for Equal Work Principle:

- Many countries have strong legal and cultural norms about equal pay for equal work

- Paying different net wages to workers based on age for the same job could be:

  * Viewed as discriminatory

  * Create legal liability risks

  * Violate workplace fairness standards

- This would make firms reluctant to adjust wages differently by age

2. Internal Equity and Wage Compression:

- Firms typically maintain internal wage structures that:

  * Have standardized pay scales

  * Define clear relationships between positions

  * Establish consistent age-based progression

- Disrupting these structures by passing tax savings only to younger workers could:

  * Create workplace tensions

  * Harm morale and productivity

  * Lead to grievances from older workers

3. Role of Labor Unions and Works Councils:

- In Western European contexts, these institutions typically:
  * Negotiate collective agreements covering all workers
  * Enforce standardized wage scales
  * Resist age-based wage differentiation
- They would likely oppose passing tax savings only to younger workers as it:
  * Violates principle of solidarity
  * Creates unwanted wage competition
  * Undermines collective bargaining power

4. Wage Reference Points:

- Industry-wide wage standards often serve as reference points
- These reference points:
  * Define "fair" wages for specific positions
  * Are used in wage-setting across firms
  * Reflect market-wide expectations
- Deviating from these standards for young workers could:
  * Signal job quality differences
  * Create recruitment difficulties
  * Lead to reputation costs

This explanation focuses on how strong institutional norms of wage fairness, supported by legal frameworks and labor market institutions, could prevent firms from passing tax savings specifically to young workers, even when they benefit from real cost savings. This is consistent with:

- The immediate implementation of the reform

- The patterns holding for new hires
- The persistence across the wage distribution
- The observed cost savings for firms

The institutional constraints effectively force firms to maintain wage parity across age groups, even when their labor costs differ due to the tax policy.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: The explanation based on collective bargaining within the union sounds promising. If you wanted to use the DiD method to verify this explanation, how would you design the DiD treatment?

To reiterate, we have the following Data: (1) For each year from 2002-2013, we have administrative data on monthly wages (net of the employer payroll tax) that firms pay to each worker, along with worker characteristics including age. The wage measure is the full-time equivalent contracted monthly wage, adjusting for hours worked. (2) We also have matched employer-employee data showing the number of workers in each age group at each firm.

Claude 3.5 Sonnet as Student:

Thank you for the feedback. I'll propose a difference-in-differences (DiD) design to test the collective bargaining explanation.

Revised Solution:

DiD Design to Test the Collective Bargaining Explanation:

Treatment Definition:

- Treatment Group: Workers in highly unionized firms/sectors
- Control Group: Workers in firms/sectors with low union presence
- Age groups: Compare workers just above and below the age threshold in both groups
- Time: Before and after the payroll tax reform

Specifically:

1. First Stage: Categorizing Firms

- Use employer-employee matched data to identify:
  * Firms covered by collective bargaining agreements
  * Firms without collective bargaining coverage
- Measure union density at firm level using:
  * Number of union members
  * Coverage of collective agreements
  * Presence of works councils

2. DiD Specification:

$wage_{ijt} = \beta_0 + \beta_1(Young_i \times Post_t) + \beta_2(Young_i \times Post_t \times Union_j) + \gamma_i + \delta_t + \theta_j + \varepsilon_{ijt}$

Where:

- $wage_{ijt}$ is the net wage of worker i in firm j at time t

- $Young_i$ indicates worker below age threshold
- $Post_t$ indicates post-reform period
- $Union_j$ indicates high union density firm
- $γ_i$, $δ_t$, $θ_j$ are worker, time, and firm fixed effects

3. Expected Results if Collective Bargaining Explanation is Correct:
- $β_1$ should be positive in low-union firms (tax savings passed to wages)
- $β_2$ should be negative (offsetting effect in unionized firms)
- Net effect $(β_1 + β_2)$ should be close to zero in unionized firms

4. Robustness Checks:
- Use different thresholds for defining high/low union density
- Compare results across industries with different bargaining structures
- Examine effects at different points in wage distribution
- Test for pre-trends in both groups

This DiD design would help verify whether collective bargaining is indeed the mechanism preventing wage adjustments by:
- Exploiting variation in union presence across firms
- Controlling for other firm and worker characteristics
- Allowing for direct test of the institutional constraints hypothesis
- Providing evidence on the mechanism through which wage-setting rigidity operates

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the *teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.*

Grade: Revise

Feedback: The context studied has near universal (~90%) union coverage. So, this strategy will not work.

Claude 3.5 Sonnet as Student:

Thank you for the feedback. Given the near-universal union coverage in this context, I'll revise my DiD design to focus on variation in the strength of collective bargaining constraints across firms/sectors while working within the high-union-coverage environment.

Revised Solution:

DiD Design Using Variation in Collective Agreement Characteristics:

1. Treatment Definition Based on Wage-Setting Flexibility:

- Treatment Group: Firms/sectors with more flexible collective agreements
  * Those with local-level wage negotiations
  * Those with performance-based pay components
  * Those with opt-out clauses in agreements
- Control Group: Firms/sectors with rigid collective agreements
  * Those with centralized industry-wide agreements
  * Those with strict wage scales
  * Those without local bargaining flexibility

2. Data Construction:

Using the administrative and matched employer-employee data:

- Categorize firms based on their collective agreement characteristics

- Focus on variation in agreement flexibility while controlling for overall union coverage

- Use detailed wage components to identify firms with more variable pay structures

3. DiD Specification:

$wage_{ijt} = β_0 + β_1(Young_i × Post_t) + β_2(Young_i × Post_t × Flexible_j) + γ_i + δ_t + θ_j + ε_{ijt}$

Where:

- $Flexible_j$ indicates firms with more flexible wage-setting arrangements

- Other variables as defined previously

4. Additional Tests:

- Compare wage responses in:

  * Firms with local vs. centralized bargaining

  * Sectors with different wage-setting cycles

  * Firms with different shares of performance-based pay

- Examine timing of wage adjustments relative to collective agreement renewal dates

This revised design:

- Acknowledges the high union coverage context

- Exploits institutional variation within the unionized sector

- Tests whether wage-setting flexibility affects tax incidence

- Could reveal whether more flexible agreements allow for better pass-through of tax savings to wages

The hypothesis is that even in a highly unionized context, firms with more flexible wage-setting arrangements might show stronger wage responses to the tax change for young workers.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: I do not have such data. This strategy is infeasible. Consider other ways in which the policy might affect different groups of firms less or more so we can exploit that variation to identify.

Claude 3.5 Sonnet as Student:

Thank you for the feedback. I'll revise my solution to focus on observable firm characteristics in the available data that might create meaningful variation in the policy's impact.

Revised Solution:

DiD Design Using Firm-Level Variation in Young Worker Intensity:

1. Treatment Definition Based on Young Worker Concentration:

- Using the matched employer-employee data showing number of workers in each age group at each firm

- Treatment intensity: Share of young workers (below age threshold) in total firm employment pre-reform

- Compare firms with high vs. low shares of young workers before the reform

Rationale:

- Firms with higher shares of young workers face larger potential cost savings

- These firms have greater incentives to adjust wages

- The magnitude of wage adjustment pressure should correlate with young worker share

2. DiD Specification:

$wage_{ijt} = β_0 + β_1(Young_i × Post_t) + β_2(Young_i × Post_t × YoungShare_j) + γ_i + δ_t + θ_j + ε_{ijt}$

Where:

- $YoungShare_j$ is the pre-reform share of young workers in firm j

- Other variables as previously defined

3. Expected Results:

- If wage-setting constraints are binding:

   * Even firms with high young worker shares won't show differential wage effects

   * This would strengthen the institutional constraints explanation

- If constraints vary with stakes:

   * Firms with higher young worker shares might show stronger wage effects

   * Would suggest constraints can be overcome when incentives are strong enough

4. Additional Analysis:

- Examine whether effects vary by:

   * Firm size (using employee counts)

   * Industry (using firm classifications)

   * Average wage levels (using wage data)

- These dimensions might interact with the ability or incentive to adjust wages

This design:

- Uses only the available administrative and matched employer-employee data

- Creates meaningful variation in policy impact

- Tests whether wage rigidity varies with the strength of incentives to adjust

- Could reveal whether institutional constraints bind differently based on firm characteristics

OpenAI o1

Researcher as Teacher:

You are a student. You have to propose a solution to the problem given to you.

Problem:

Policy: In country A, employers must pay a payroll tax of 31% on their workers' wages before 2007. From July 2007, this employer-paid payroll tax was reduced to 21% for workers aged 25 and under, while remaining at 31% for older workers. From January 2009, the payroll tax was further reduced to 15% for workers aged 26 and under, while remaining at 31% for older workers.

Data: (1) For each year from 2002-2013, we have administrative data on monthly wages (net of the employer payroll tax) that firms pay to each worker, along with worker characteristics including age. The wage measure is the full-time equivalent contracted monthly wage, adjusting for hours worked. (2) We also have matched employer-employee data showing the number of workers in each age group at each firm.

Key Empirical Facts:

After the reform, gross wages (wages + payroll tax) show a clear discontinuous drop at the age threshold

Net wages remain continuous across the age threshold.

These patterns hold when following the same individual workers over time, for new hires only, and at all points in the wage distribution.

Context: This is a developed western European economy with well-functioning capital markets and high ease of doing business.

Automatic and immediate implementation of the tax cut through government payroll software used by all employers.

Question: We want to study whether the reduction in employer payroll taxes for younger workers led to an increase in their wages (net of payroll tax). I plotted wages by age groups over time and found that while wages generally increase smoothly with age, this relationship remains smooth across the age threshold even after the reform. A difference-in-differences analysis comparing workers just above versus just below the age cutoff shows no significant effect on net wages. Why might this identification strategy fail to detect wage effects of the policy even if they existed?

OpenAI o1 as Student:

One key challenge is that the DiD strategy assumes that wages of "just younger" and "just older" workers would have followed parallel trends in the absence of the tax cut. In reality, several factors can break this parallel trends assumption and obscure any genuine wage effects:

• Differences in worker composition around the cutoff: Workers who are 24–25 might differ systematically (e.g., in seniority, tenure, education) from those who are 26–27. If these differences affect wage growth independently of the policy, the DiD comparison may confound true policy effects with other age-related wage dynamics.

• Institutional or contractual wage rigidities: Wages may be set over longer horizons (e.g., under collective bargaining agreements or annual contracts). In that case, the immediate impact of a payroll tax reduction might accrue primarily to employers rather than being passed on immediately (or at all) to workers in the form of higher net pay.

• Age-based selection and transitions: The policy thresholds move with the worker's age. A "just younger" individual at one point in time is "just older" after turning 26, so there can be compositional shifts as employees cross the age cutoff. These transitions weaken the clean treatment-control comparison needed for DiD.

• Other time-varying confounders: If macroeconomic conditions or industry-specific wage shocks evolve differently for the younger vs. older groups, then even slightly different trends may mask the impact of the tax cut, especially if it is relatively small compared to broader wage fluctuations.

Thus, although the DiD design compares younger workers (eligible for the lower payroll tax) with slightly older workers (ineligible), these groups may not truly provide a valid counterfactual for each other. Hence, even if the tax cut did exert upward pressure on younger workers' net wages, it may remain undetected when using a straightforward DiD around the age threshold.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no *response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.*

Grade: Revise

Feedback: The paper's empirical work rules out these methodological concerns. The wage-age relationship remains perfectly smooth at the threshold even when following individual workers over time, and pre-trends are parallel.

OpenAI o1 as Student:

One possible reason the DiD approach might still fail to detect wage effects—despite controlling for composition changes, having parallel pre-trends, and finding no visible discontinuity in the wage-age relationship—is that younger workers' wages could be determined by institutional or contractual mechanisms that make them relatively rigid even in the presence of a tax cut. For example:

• Collective bargaining or minimum wage floors. In settings where wage setting is collectively bargained over multi-year horizons, or where minimum wages bind, there might be little or no short-run wage adjustment even if employers benefit from lower payroll taxes.

• Tax incidence favoring employers. Even if labor demand for younger workers rises, the incidence of the tax cut might accrue primarily to the employer (e.g., through lower labor costs), rather than being passed through to workers as higher net wages.

• Focus on other margins of adjustment. Employers might have responded to the tax reform by altering hiring, hours, or other forms of compensation (bonuses, training opportunities, benefits) rather than raising base wages immediately. If the DiD focuses solely on wages, it may miss adjustments along these other margins.

Hence, even with a robust identification strategy and evidence that pre-trends and composition effects are well-controlled, it is still possible that any real wage gains from the policy could have been muted by these institutional or contractual features—leading to a null result in the data.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: The paper shows firms did receive real cost savings from the tax cut (visible in gross wages), and the wage measure is comprehensive. Consider what features of collective bargaining might prevent firms from passing these savings specifically to young workers.

OpenAI o1 as Student:

Even if firms experience genuine cost savings, collective bargaining agreements often treat workers within similar roles or seniority levels identically, regardless of age. Contracts may specify wage scales by job grade or tenure, effectively preventing employers from offering different wages solely based on lower tax rates for younger employees. As a result, even though employers realize savings from reduced payroll taxes, they might not be permitted—under collectively bargained rules—to selectively increase wages for younger workers. Instead, any cost savings might effectively spread across all workers (e.g., through firm-wide pay increases or other benefits) or accrue to the employer if they are not obligated to adjust wages.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: Your explanation about collective bargaining preventing differential wages by age is promising. If you wanted to use the DiD method to verify this explanation, how would you design the DiD treatment?

To reiterate, we have the following Data: (1) For each year from 2002-2013, we have administrative data on monthly wages (net of the employer payroll tax) that firms pay to each worker, along with worker characteristics including age. The wage measure is the full-time equivalent contracted monthly wage, adjusting for hours worked. (2) We also have matched employer-employee data showing the number of workers in each age group at each firm.

OpenAI o1 as Student:

One way to test whether collective bargaining constraints prevent passing tax-cut savings on to younger workers is to exploit differences in bargaining structures across firms. Specifically, you could define your “treatment” based on a firm-level measure of collective bargaining rigidity (for example, whether the firm is subject to a collective agreement with uniform wage scales). Then:

1) Identify two groups of firms:

• High-rigidity firms: Those bound by industry- or firm-level agreements preventing differential wage setting by age.

• Low-rigidity firms: Those with more flexible wage setting (e.g., no rigid age-based pay scales).

2) Within each group of firms, use a DiD comparing:

• Younger workers eligible for the reduced payroll tax (treatment group).

• Slightly older workers not eligible (control group).

3) Compare the DiD estimates between the high-rigidity and low-rigidity groups.

• If collective bargaining truly restricts age-based wage adjustments, you would expect near-zero wage effects for young workers in high-rigidity firms (even though those firms do save on payroll taxes).

• In contrast, low-rigidity firms might pass at least some portion of these savings on as higher wages for the younger cohort if institutional constraints are weaker.

Formally, this can be set up as a “difference-in-differences-in-differences” approach:

• First difference: younger vs. older workers (within the same firm group).

• Second difference: pre- vs. post-policy periods (e.g., before vs. after July 2007 or January 2009).

• Third difference: high-rigidity vs. low-rigidity firms.

By combining the matched employer-employee data (to classify firm-level bargaining structures and identify each worker’s wages over time) with the policy changes (July 2007 and January 2009), you can directly test whether more flexible firms exhibit any wage response for young workers that is absent in more rigid, collectively bargained environments.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: Revise

Feedback: I do not have such data. This strategy is infeasible. Consider other ways in which the policy might affect different groups of firms less or more so we can exploit that variation to identify.

OpenAI o1 as Student:

Here is an alternative DiD strategy that exploits variation we do observe, namely the age composition of each firm:

1) Define “treatment intensity” at the firm level based on the proportion (or total count) of younger workers affected by the tax cut. For example, you might classify firms above a certain threshold of young-worker share as “high-intensity” and those below it as “low-intensity.”

2) Compare changes in net wages for younger workers (eligible for the lower payroll tax) versus older workers (ineligible) before and after the policy. However, split the sample by high-intensity vs. low-intensity firms, and compare the difference in these differences across the two groups. In effect, you would have:

- Younger vs. older workers (within each firm group)
- High-intensity vs. low-intensity firms
- Pre vs. post policy

3) If collective bargaining or wage rigidity is partly offset by the magnitude of cost savings, firms with a larger share of younger workers might have a stronger incentive—or at least a greater ability—to pass through some fraction of the tax cut to young employees. By contrast, firms employing few younger

workers might find the policy savings too small to justify disturbing their existing pay structure.

4) Empirically, implement this by estimating a triple-differences (or two separate DiD analyses) that interacts:

(i) an indicator for being a younger worker,

(ii) an indicator for the post-reform period(s),

(iii) an indicator for being a high-intensity firm.

A statistically significant positive coefficient on the triple interaction would suggest at least partial wage pass-through for young workers in firms with a high share of younger employees—a channel you might not detect if you only compared younger vs. older workers, or only high-intensity vs. low-intensity firms in isolation.

Problem C

LLM-Human Student-Teacher Dialog

OpenAI o1

Researcher as Teacher:

You are a student. You have to provide a solution to the problem given to you.

Consider a generator agent that needs to make unit commitment (ON/OFF) and economic dispatch decisions for N = 24 time periods ahead based on expected electricity prices. The generator has the following characteristics:

1. Quadratic operating costs: $C(S) = \alpha S^2 + \beta S + \gamma$, where S is the power generated

2. Fixed startup costs when turning ON

3. Fixed shutdown costs when turning OFF

4. Minimum and maximum generation limits when ON

5. The decision at each period affects profitability of future periods

The objective is to maximize profit across all N periods while respecting these operational constraints.

How would you approach designing an efficient solution algorithm for this problem?

OpenAI o1 as Student:

A practical way to tackle this type of unit-commitment and economic-dispatch problem (with a single generating unit over 24 time periods, including startup/shutdown costs and quadratic operating costs) is to combine discrete (ON/OFF) decisions with a continuous dispatch variable. Below is a high-level outline of an efficient design approach:

1) Formulate as a Mixed-Integer Quadratic Program (MIQP)

• Introduce a binary variable, say u_t, for each period t, where $u_t = 1$ if the unit is ON in period t and $u_t = 0$ otherwise.

• Introduce a continuous variable, say S_t, for the output (MW) in period t.

• The operating cost for each period can be modeled as $C(S_t)=\alpha S_t^2 + \beta S_t + \gamma$, and incorporated in the objective function.

• Include startup and shutdown cost terms. For example, you can define binary variables to indicate transitions (e.g. $v_t = 1$ if the unit turns ON at period t, $w_t = 1$ if the unit turns OFF) and multiply them by the respective startup or shutdown cost.

• Enforce S_t to be zero whenever $u_t = 0$ (e.g. through a big-M style constraint or other bounding technique).

• Impose generation limits when $u_t = 1$, i.e. $\text{min\_gen} \le S_t \le \text{max\_gen}$.

2) Objective Function

Maximize total profit:

$\max \sum_{t=1}^{N} \Bigl(p_t \cdot S_t - C(S_t)\Bigr)

\;-\; \sum_{t=1}^{N} (\text{startup_cost}_t + \text{shutdown_cost}_t),

$

where p_t is the (forecasted) electricity price in period t and $C(S_t)$ is the quadratic cost in that period.

3) Operational Constraints and Logical Constraints

• Startup/shutdown constraints: ensure v_t and w_t correctly represent transitions from u_{t-1} to u_t.

• Minimum up/down times (if relevant): for instance, when a generator is switched ON, it may have to remain ON for a certain number of consecutive periods. These constraints can be encoded via inequalities linking u_t variables over time.

4) Solve with a Commercial or Open-Source Solver

• Because this is a single-generator problem over 24 hours, a direct MIQP formulation is often tractable with modern MILP/MIQP solvers (e.g., CPLEX, Gurobi, or open-source solvers like CBC for linear approximations, or IPOPT plus a branch-and-bound framework for quadratic terms).

• If needed, you can approximate the quadratic operating cost with piecewise linear segments to convert it into a Mixed-Integer Linear Program (MILP), which may be faster in some solvers.

5) Alternative Approaches (Depending on Complexity)

• Dynamic Programming: If the problem remains singled-out to one generator, you could define a DP state capturing the ON/OFF status and how many consecutive hours it has been ON or OFF, then decide the optimal dispatch. However, once minimum up/down times and more complicated startup/shutdown costs are included, the state space can grow.

• Lagrangian Relaxation or Benders Decomposition: Typically used in larger multi-unit problems. For a single generator with 24 periods, a direct MIQP approach is often simpler.

In practice, the above steps—defining binary ON/OFF decisions, continuous dispatch variables, cost structures, plus constraints—provide a clear path to an implementable unit commitment solution. Modern solvers can handle the resulting MIQP or MILP (if linearized) within reasonable time for a 24-hour scheduling horizon.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: FAIL

Feedback: The solutions you propose are approximate. Only exact solutions are acceptable.

OpenAI o1 as Student:

One way to obtain an exact solution, yet keep computations tractable for a single generator over 24 hours, is to implement a discrete-time Dynamic Programming (DP) approach that enumerates all feasible ON/OFF sequences while respecting constraints. Below is a sketch of how to set this up in a manner that can be optimized for a microcontroller:

1) Define the State

Let the state at time t be (u, m), where

• u ∈ {0, 1} is the ON/OFF status (0 = OFF, 1 = ON).

• m is an integer tracking how many consecutive time periods the generator has been ON (or OFF), which enables enforcement of minimum up/down times.

2) State Transitions and Recurrence

From state (u, m) at time t, you can either remain in the same status or switch status (if feasible, paying startup/shutdown costs). Then compute the next state (u', m') for time t+1 accordingly:

• If you stay ON (u' = 1), you dispatch an optimal power level S_t (within min_gen ≤ S_t ≤ max_gen) to maximize instantaneous profit $p_t \cdot S_t - C(S_t)$.

• If you switch OFF (u' = 0), you pay any applicable shutdown cost and do not generate power ($S_t = 0$).

The DP recurrence for maximum profit V(t, u, m) from period t onward is:

V(t, u, m) = max over feasible transitions { Immediate Profit + V(t+1, u', m') }.

3) Enforce Quadratic Cost and Profit Exactly

• For each potential power level S ∈ {min_gen, …, max_gen} (discretized at a suitable step size if necessary), compute cost quadratically:

$C(S) = \alpha S^2 + \beta S + \gamma$.

• The revenue is $p_t \times S$, so the net at period t is $p_t \cdot S - (\alpha S^2 + \beta S + \gamma)$ - (startup or shutdown cost if triggered).

• Because we're enumerating feasible dispatch levels for each ON state, this solution is exact (up to any chosen discretization for S).

4) Implementation Details for a Microcontroller

• DP Array Size: For each t from 1 to 24, and for each possible (u, m) pair, store V(t, u, m). Even accounting for up/down time constraints, the total number of states is manageable for 24 periods and a single unit.

• Minimize the number of S values to iterate over by using either small discrete steps or by enumerating only a handful of typical operating points (e.g., min, mid, max generation).

• Recurrence Computation: Proceed either forward or backward in time. A backward approach:

V(24, u, m) = best instantaneous profit at final period for state (u, m).

Then for $t = 23$ down to 1, compute $V(t, u, m)$ using the above transition logic.

• The final answer is $\max(V(1, u, m))$ over all valid (u, m) initial states (e.g., generator OFF with zero consecutive hours if that is the usual condition).

By enumerating states, transitions, and discrete power levels, you get an exact DP solution. On a microcontroller, you can keep the DP table in a small 2D or 3D array, and carefully optimize the transitions to reduce computational load. This approach ensures exactness (given the finite set of S values) and avoids the complexities of solving a large MIQP on limited hardware.

Researcher as Teacher:

You are a student. For the given problem, your teacher's feedback is given below. If your teacher's feedback says FAIL, propose a new solution taking into account the teacher's reason for rejection. If your teacher's feedback says PASS, then make no response, and if your teacher's feedback says REVISE, then follow the instructions to revise your solution.

Grade: FAIL

Feedback: Discretizing power levels will yield an approximate solution.

OpenAI o1 as Student:

Below is a sketch for an exact Dynamic Programming (DP) approach that avoids discretizing power levels:

1) Closed-Form Optimal Dispatch for Each Period

When the generator is ON in period t with price p_t, the power level S_t that maximizes that period's net profit $p_t \cdot S_t - (\alpha S_t^2 + \beta S_t + \gamma)$ can be found by setting the first derivative to zero and clamping within minimum/maximum limits:

Let the unconstrained optimum be

$\bar{S} = (p_t - \beta) / (2\alpha)$.

Then

$S_t^* = \min(\max(\bar{S}, min\_gen), max\_gen)$.

This gives the unique exact best dispatch level for each period, given that the unit is ON.

2) Dynamic Programming Formulation

a) State Definition: Define the state at time t as (u, m), where

- $u \in \{0, 1\}$ is the ON/OFF status.
- m is the number of consecutive hours the generator has been in status u (used to enforce any minimum up/down times if needed).

b) Transition Decisions: From state (u, m) at time t, you can stay ON (u' = 1) or OFF (u' = 0) at time t+1, provided you respect minimum up/down constraints.

c) Immediate Cost/Profit:

- If you remain ON, compute the exact optimal S_t^* from step 1, then the "stage profit" is

  $p_t \cdot S_t^* - (\alpha(S_t^*)^2 + \beta S_t^* + \gamma)$.

- If you switch ON from OFF, add the startup cost.
- If you switch OFF from ON, add the shutdown cost.
- If OFF, no power is generated ($S_t = 0$).

d) DP Recurrence: Let V(t, u, m) be the maximum total profit from period t through period N given state (u, m) at period t. Then

V(t, u, m) = max (over valid transitions to (u', m')) of { [Immediate Profit at t] + V(t+1, u', m') }.

e) Boundary Conditions: At t = N (final period), V(N, u, m) is simply the single-period profit (ON or OFF) plus any transition cost.

3) No Discretization of Power

Because S_t* is computed via closed-form for each period you decide to be ON, there is no approximation from enumerating or discretizing power levels. This yields an exact solution for each time period's power dispatch.

4) Implementation on a Microcontroller

- Keep a DP table for V(t, u, m). The total size is 24 × number_of_states_for_m × 2 for ON/OFF. Even with minimal enforcement of up/down times, this remains manageable for 24 hours and one generator.
- At each DP step, compute S_t* directly with the closed-form formula. Update the DP table entry with the resulting exact profit.
- Once the table is complete, the optimal commitment and dispatch schedule is obtained by backtracking through the stored transitions starting from argmax[V(1, u, m)].

This method yields an exact solution without discretizing power output, avoids the complexities of solving a full MIQP, and remains feasible for a single generator over a 24-hour horizon on relatively constrained hardware.