Value Proposition:
Allocator-Aware (AA) Software

John Lakos

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Abstract

The performance benefits of supplying local allocators are well-known and substantial [Lakos, ACCU'17]. Still, the real-world costs associated with orchestrating the integration of allocators throughout a code base, including training, supporting tools, enlarged interfaces (and contracts), and a heightened potential for inadvertent misuse cannot be ignored. Despite substantial upfront costs, when one considers collateral benefits for clients – such as rapid prototyping of alternative allocation strategies – the case for investing in a fully *allocator-aware* (*AA)* software infrastructure (SI) becomes even more compelling. Yet there remain many "concerns" based on hearsay or specious conjecture that are either overstated or incorrect.

In this densely fact-infused talk, we begin by introducing a familiar analogy to drive home the business case for *AA*SI. Next we identify four syntactic styles based on three distinct models: C++11, C++17, and a brand new language-based approach being developed by Bloomberg for C++23 (or later). Costs – both real and imagined – will be contrasted with performance as well as other important ("collateral") benefits. The talk will conclude with a closer look at the economic imperative of pursuing a low-cost language-based alternative to *AA* software in post-modern C++.

Purpose of this Talk

Current state of affairs…

- Local Allocators -> performance!! [Lakos, CppNow'17]
- There are, however, *real-world costs*
- There are also important *collateral benefits*
- Yet there remain "concerns" (a.k.a. F.U.D.)

Purpose of this Talk

What we will do today …

- Present the four *AA* software styles
- Separate real from imagined costs
- Discuss important collateral benefits of *AA*
- Address common “concerns” surrounding *AA*
- Advocate for supporting *AA*SI today
- Make business case using detailed analogy
- Hint at what C++2y allocators might look like

Outline

1. Introduction
2. Styles for *Allocator-Aware (AA)* Software
3. Performance Benefits
4. Costs
5. Collateral Benefits
6. “Concerns”

Outline

1. Introduction
2. Styles for *Allocator-Aware (AA)* Software
3. Performance Benefits
4. Costs
5. Collateral Benefits
6. “Concerns”

Introduction

Dynamic memory allocation is important!

- **`new`/`delete`** usually adequate
- Custom allocation is sometimes advantageous
  - (and sometimes it's absolutely necessary)
- But implementing custom allocation is costly.
- Thus, we are motivated to create (now): *Allocator-Aware (AA) Software* Infrastructure
  - *(and soon): BB20V* (Bloomberg's 2020 Vision)

Introduction

Two approaches to custom memory allocation:

- Design bespoke (custom) data structures when needed.
  - Best possible performance
  - High development/maintenance costs
- Build on *Allocator Aware (AA)* components
  - *Nearly* best possible performance
  - Much lower costs

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- Design bespoke (custom) data structures when needed.
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- Build on *Allocator Aware (AA)* components
  - *Nearly* best possible performance
  - Much lower costs **+ some collateral benefits**

Introduction

Airline Analogy to *Allocator Awareness (AA)*:

- *First Class*
  - Best possible
- *Economy*
  - Cheapest possible

Introduction

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Client Perspective

Introduction

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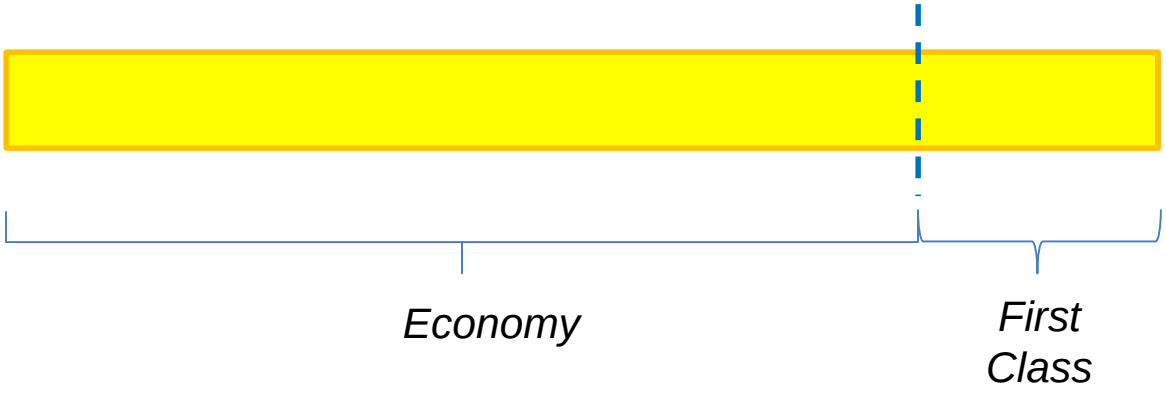

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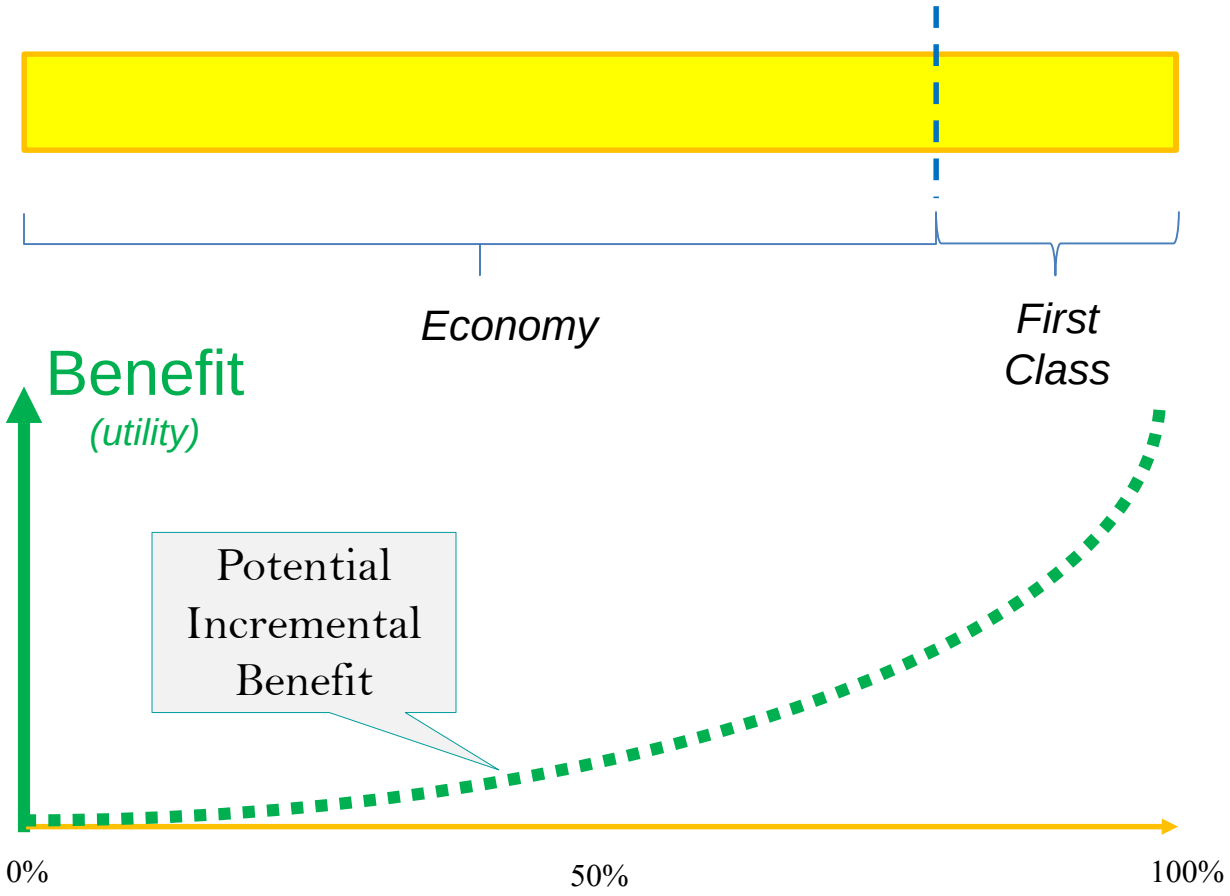

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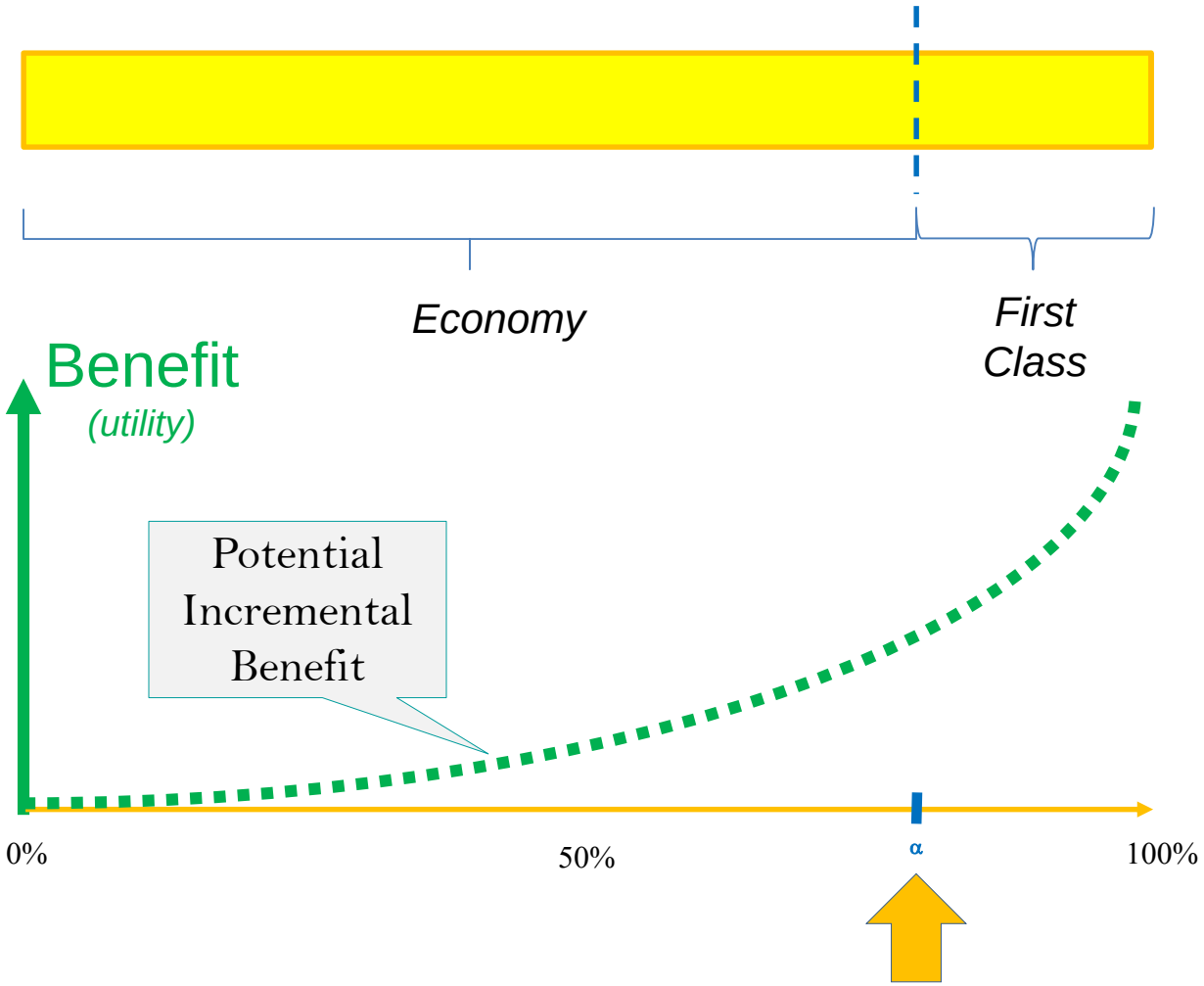

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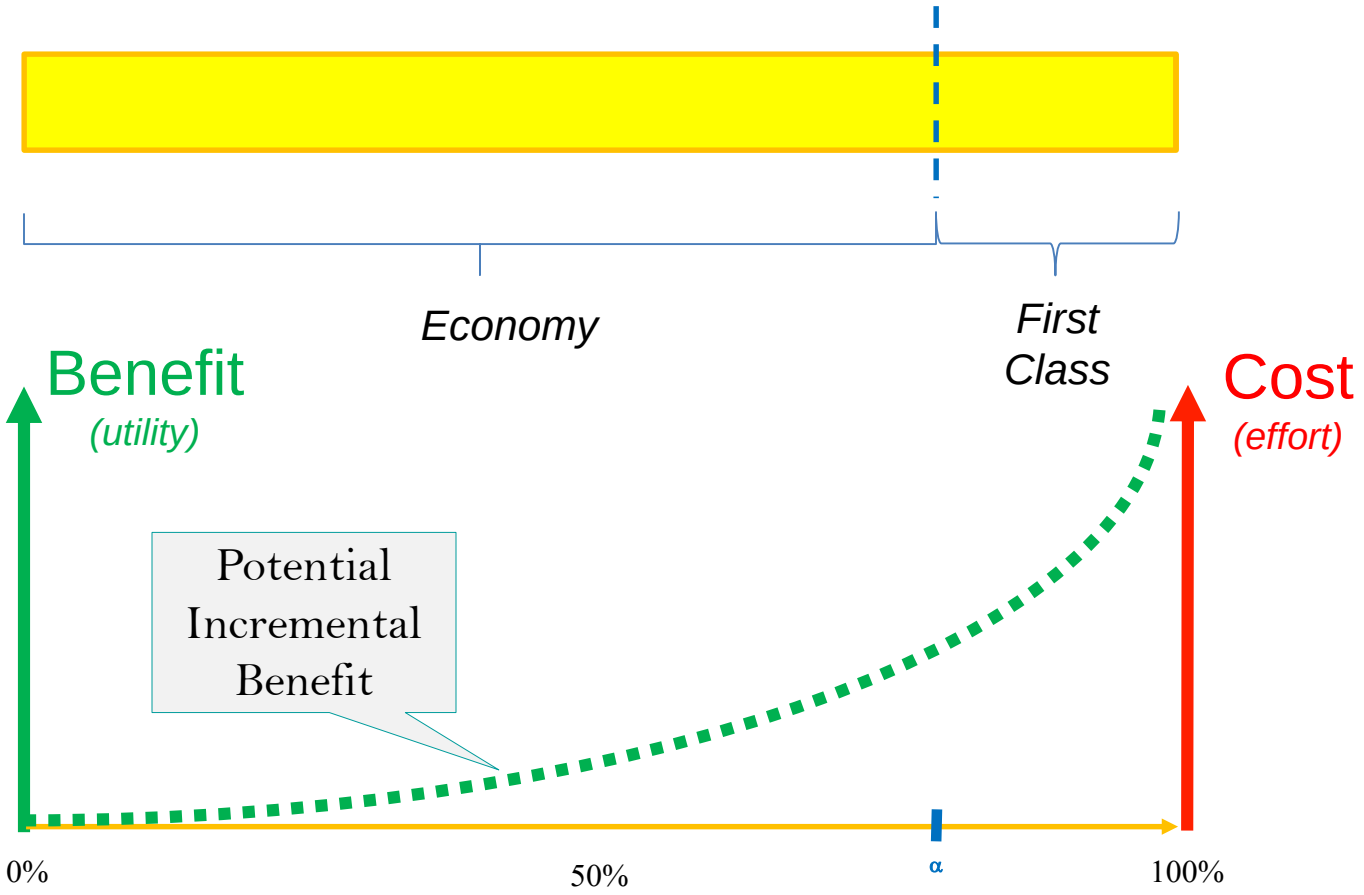

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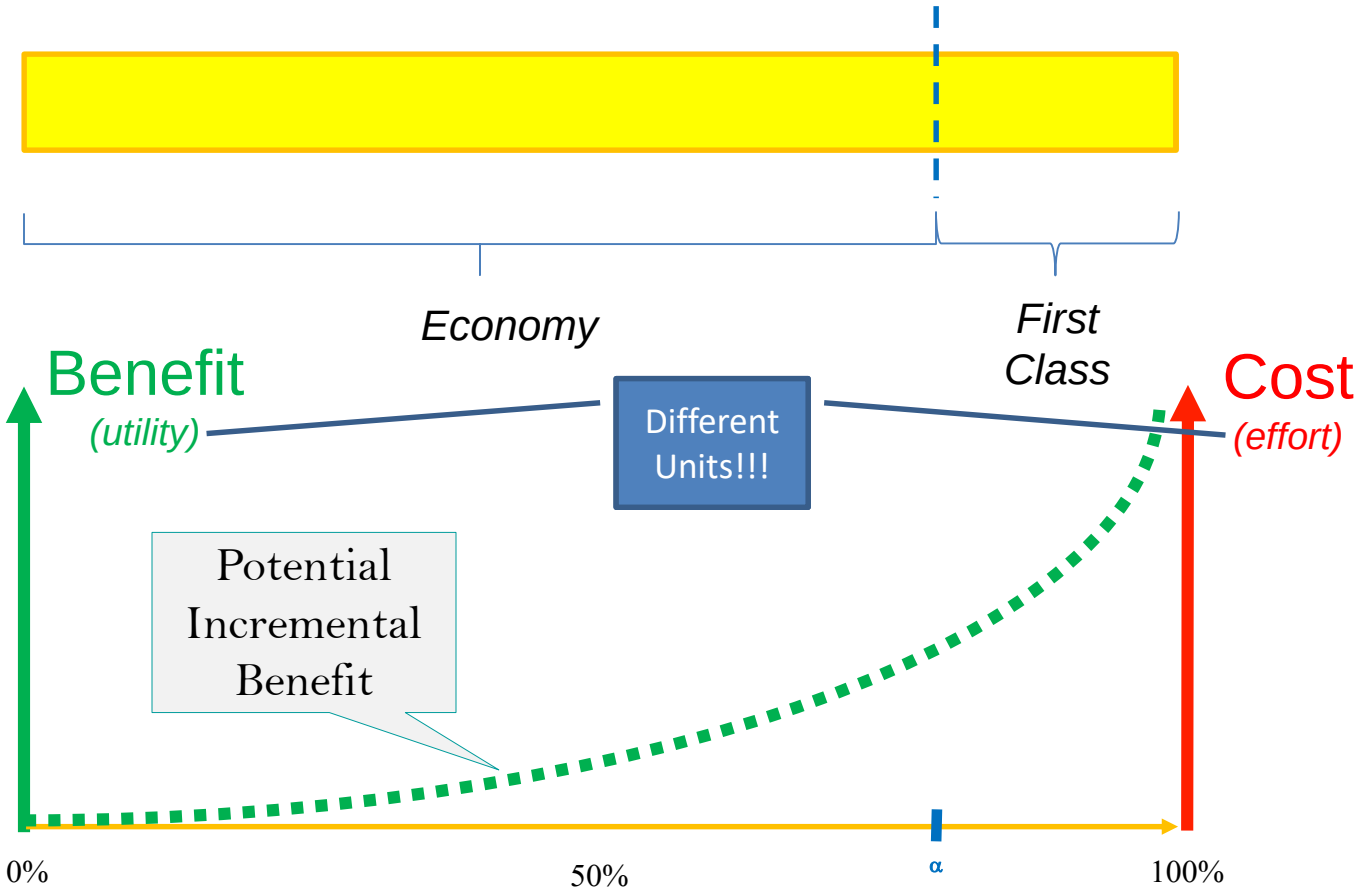

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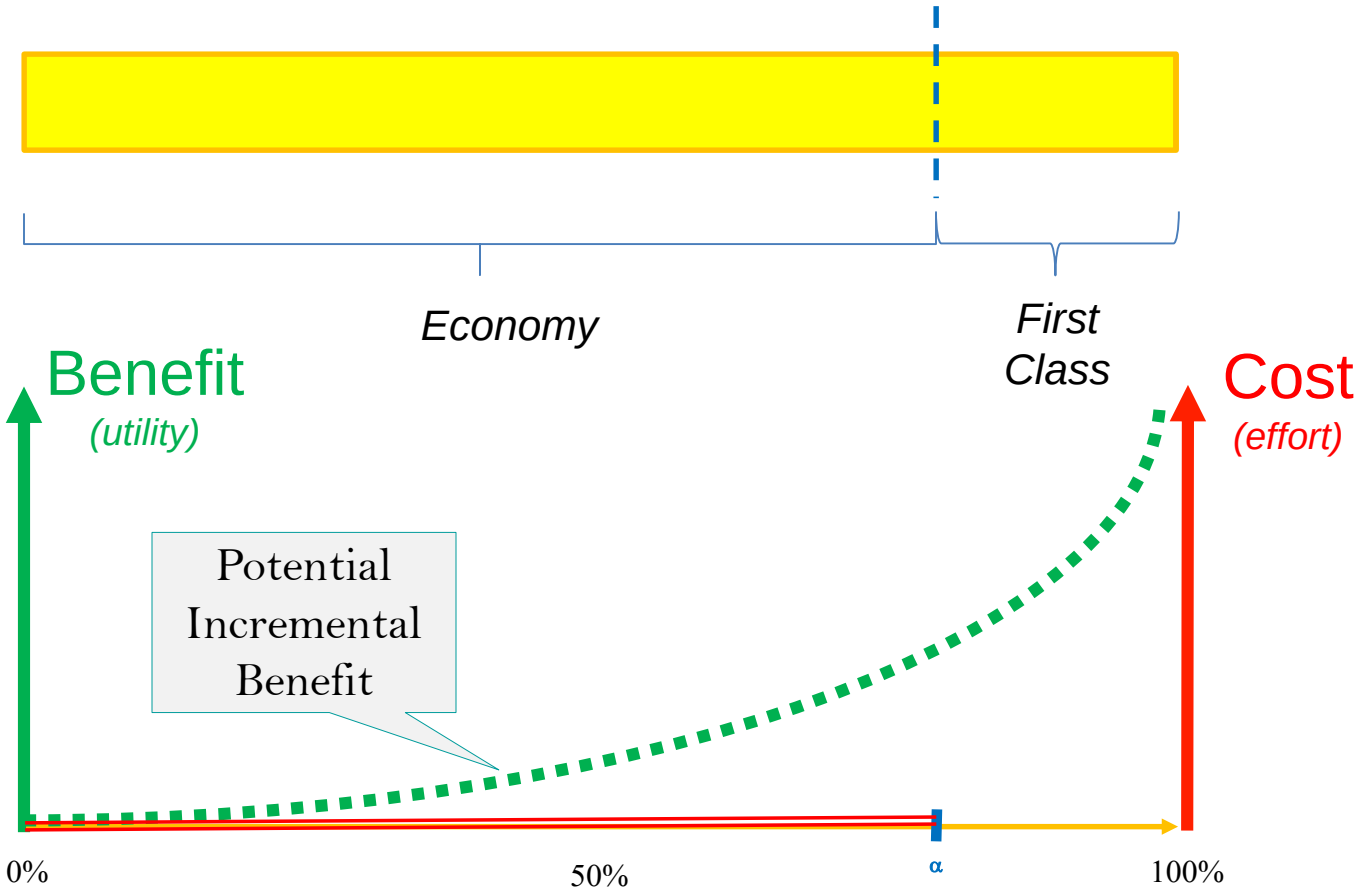

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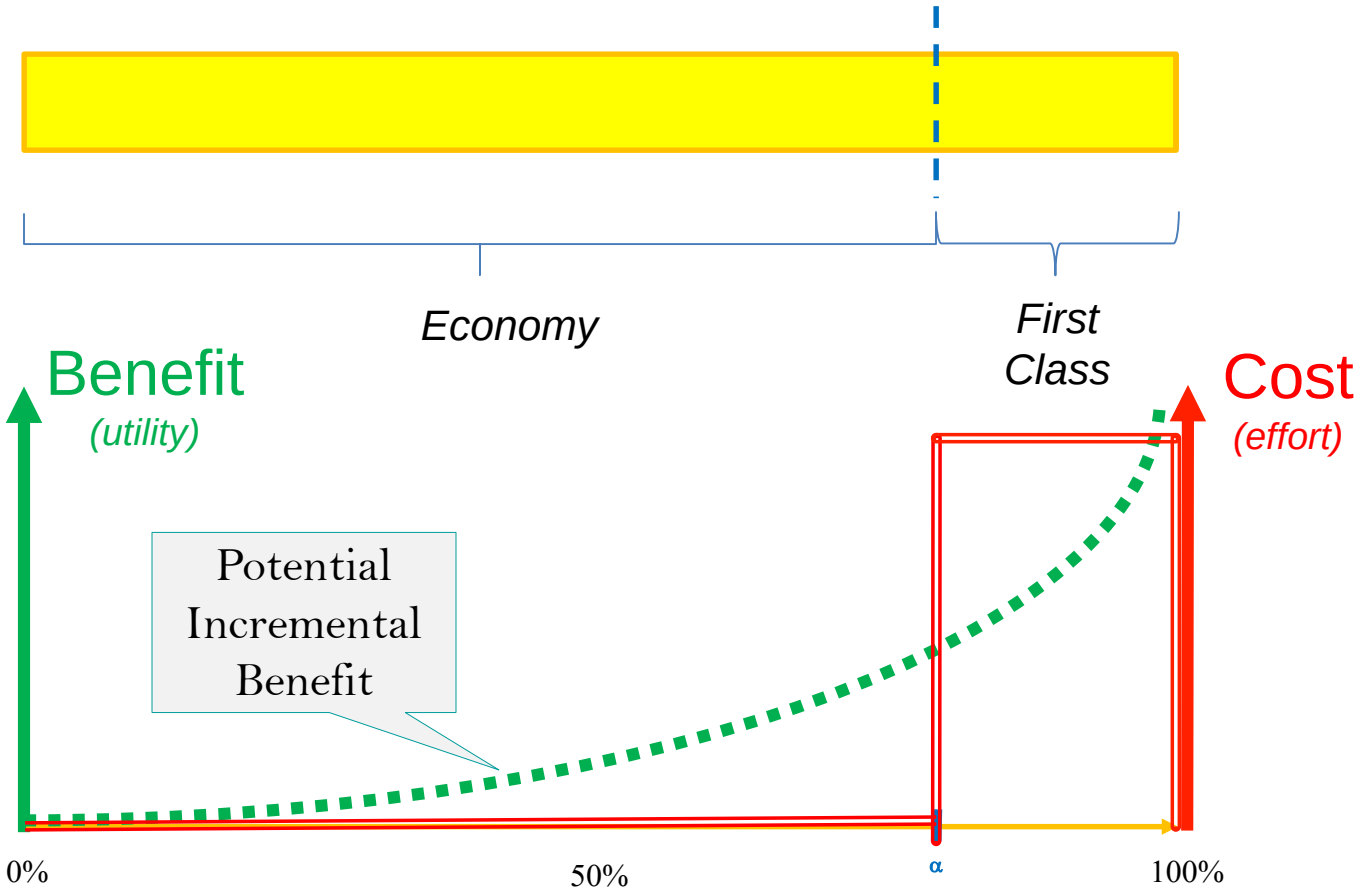

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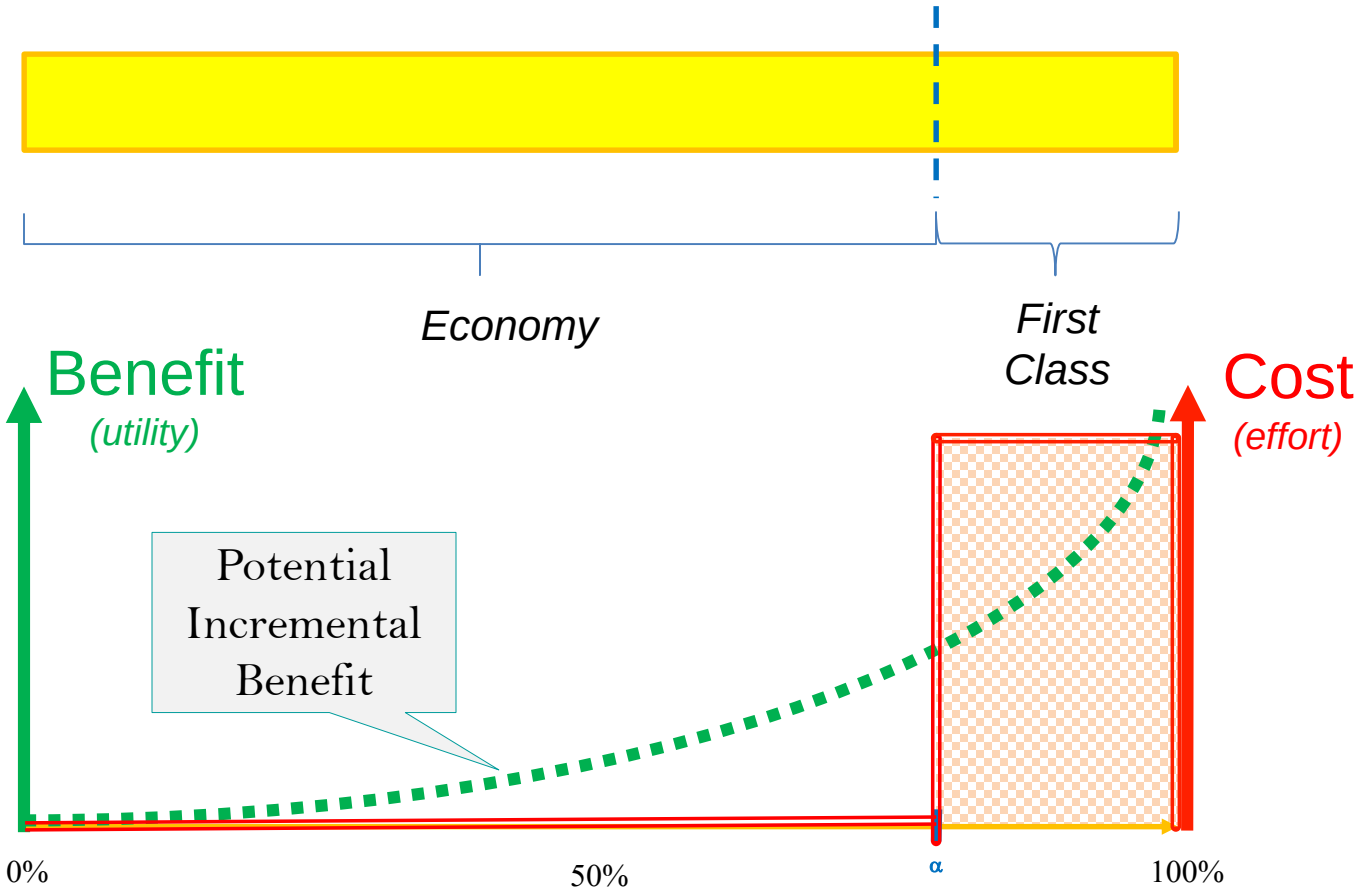

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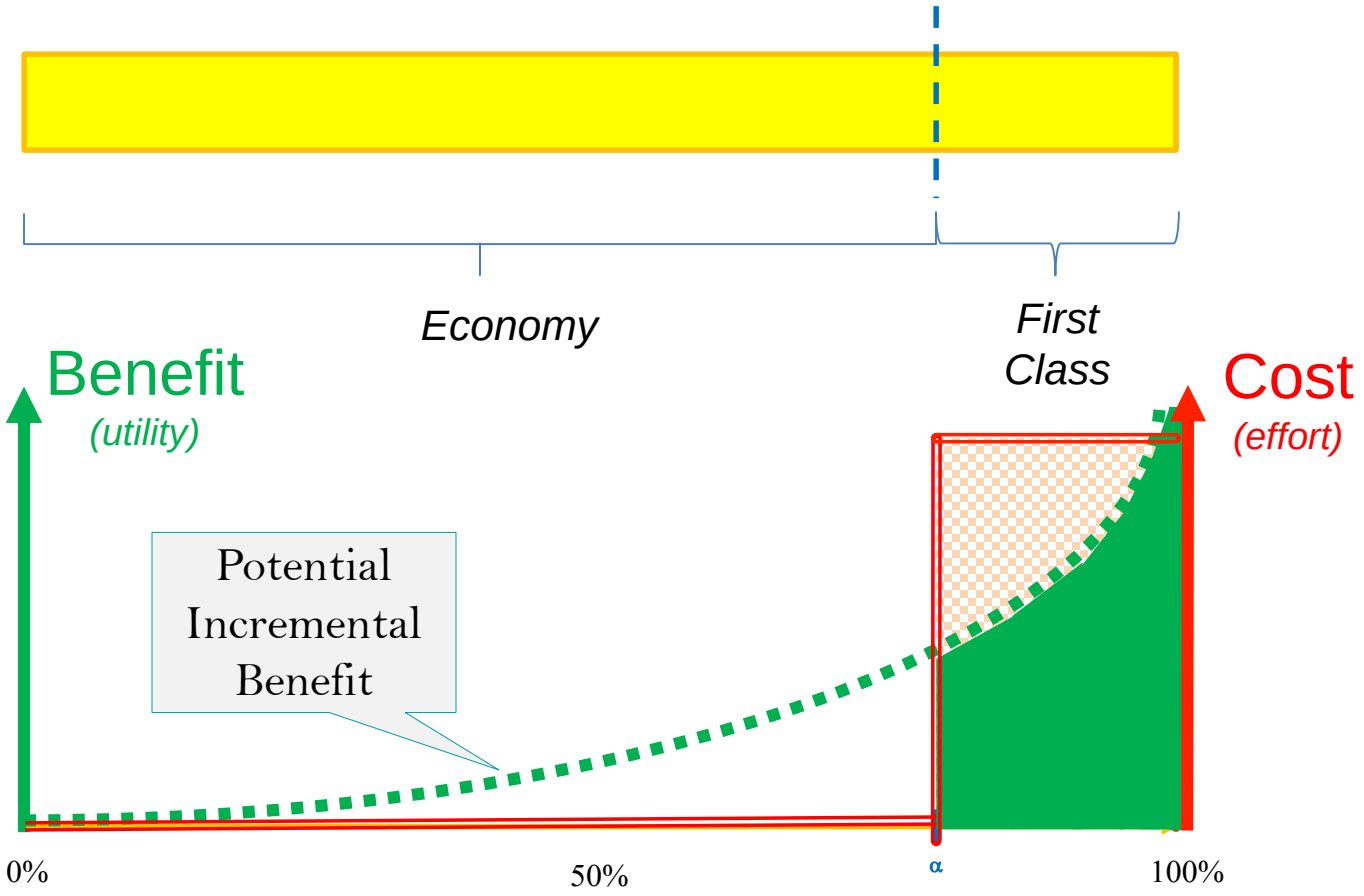

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Airline Analogy to *Allocator Awareness (AA)*:

- *First Class*
  - Best possible
- *Economy*
  - Cheapest possible
- ***Business Class* and *Premium Economy***
  - **Almost as good as first class**
  - **Costs just slightly more than *Economy***

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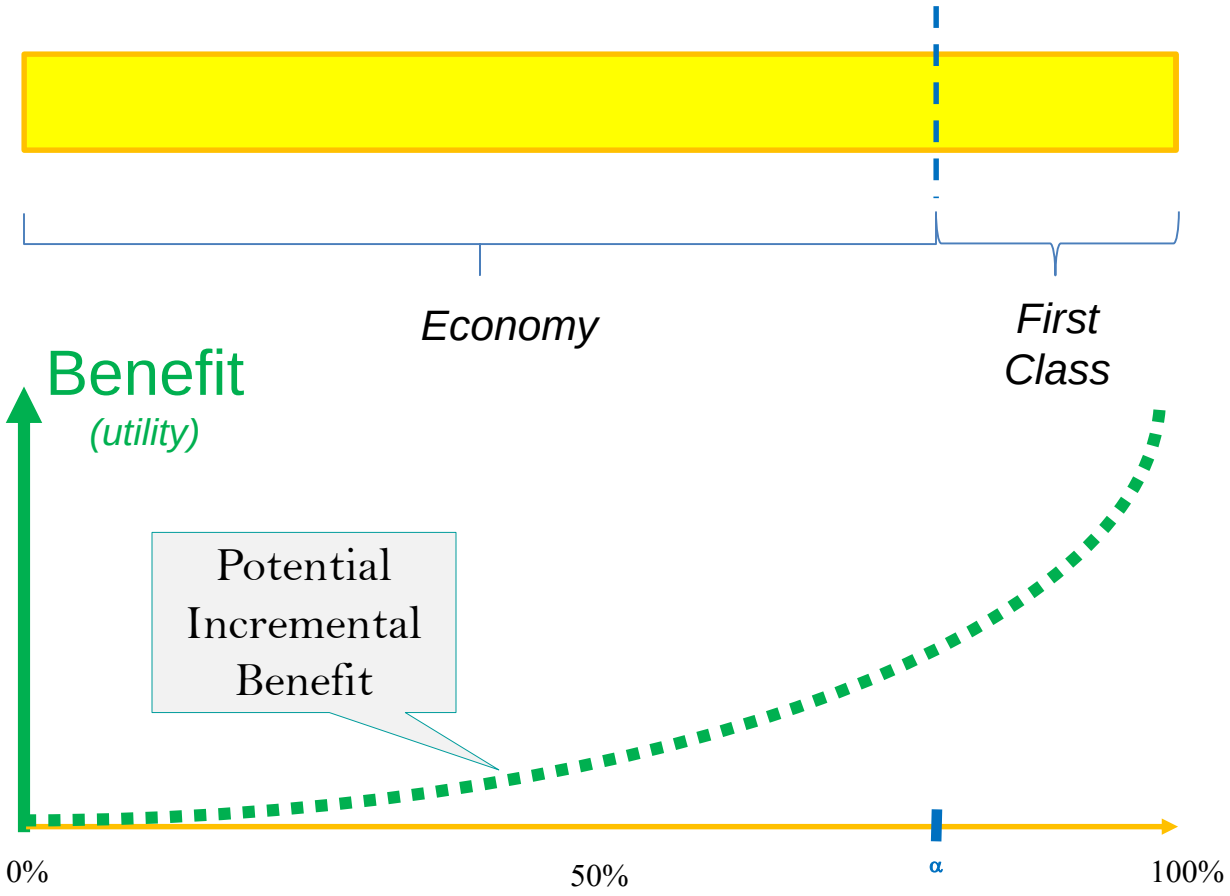

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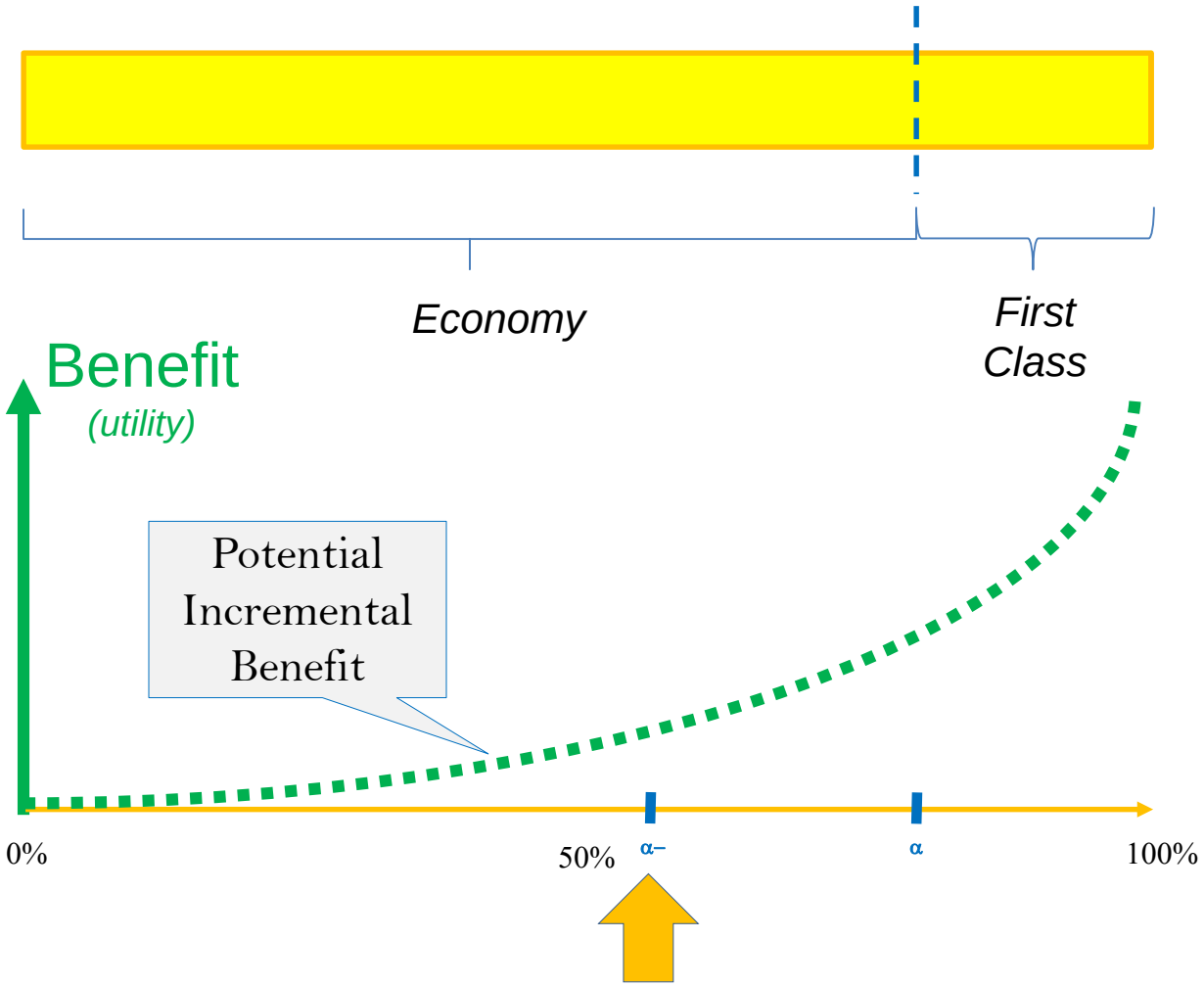

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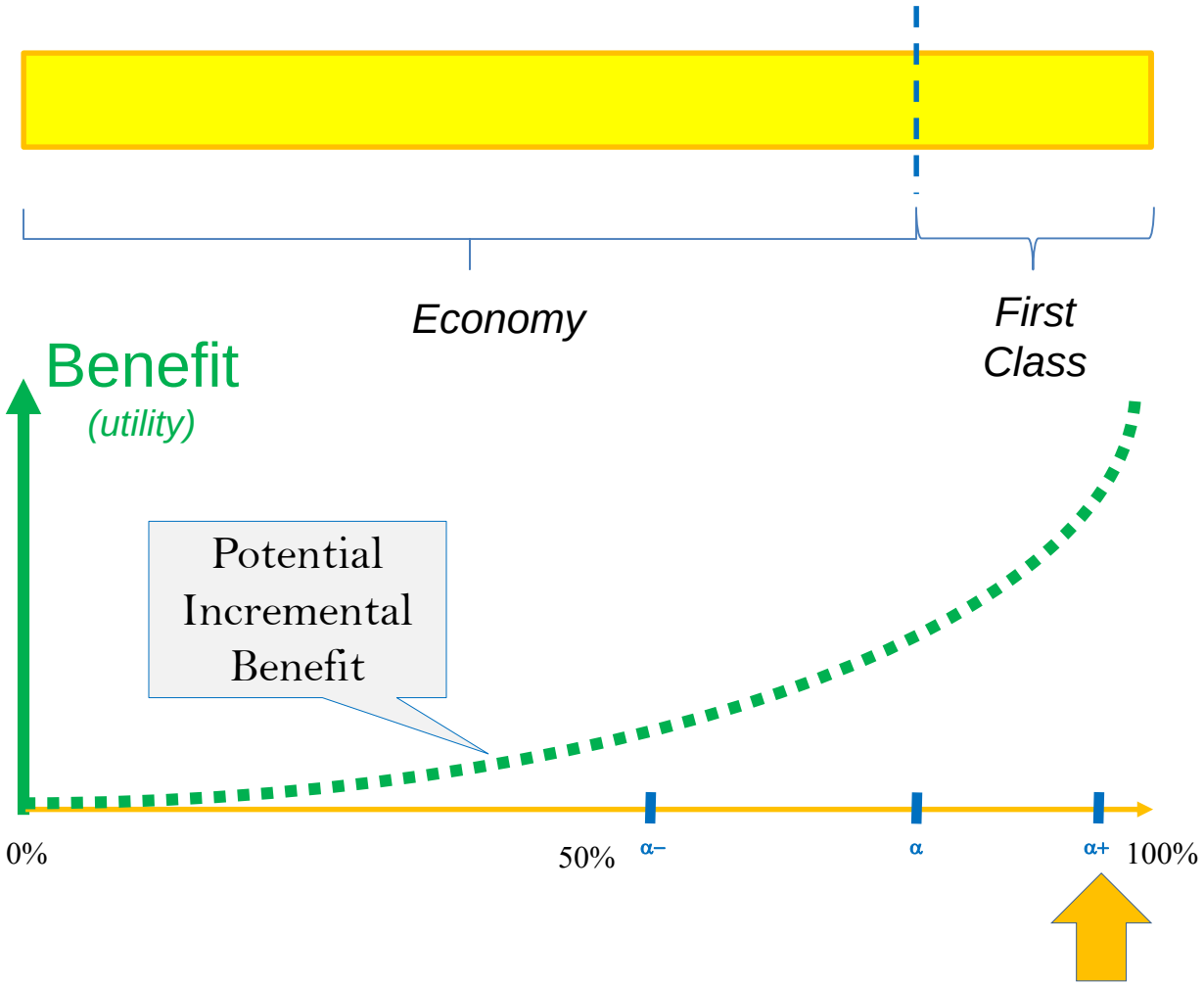

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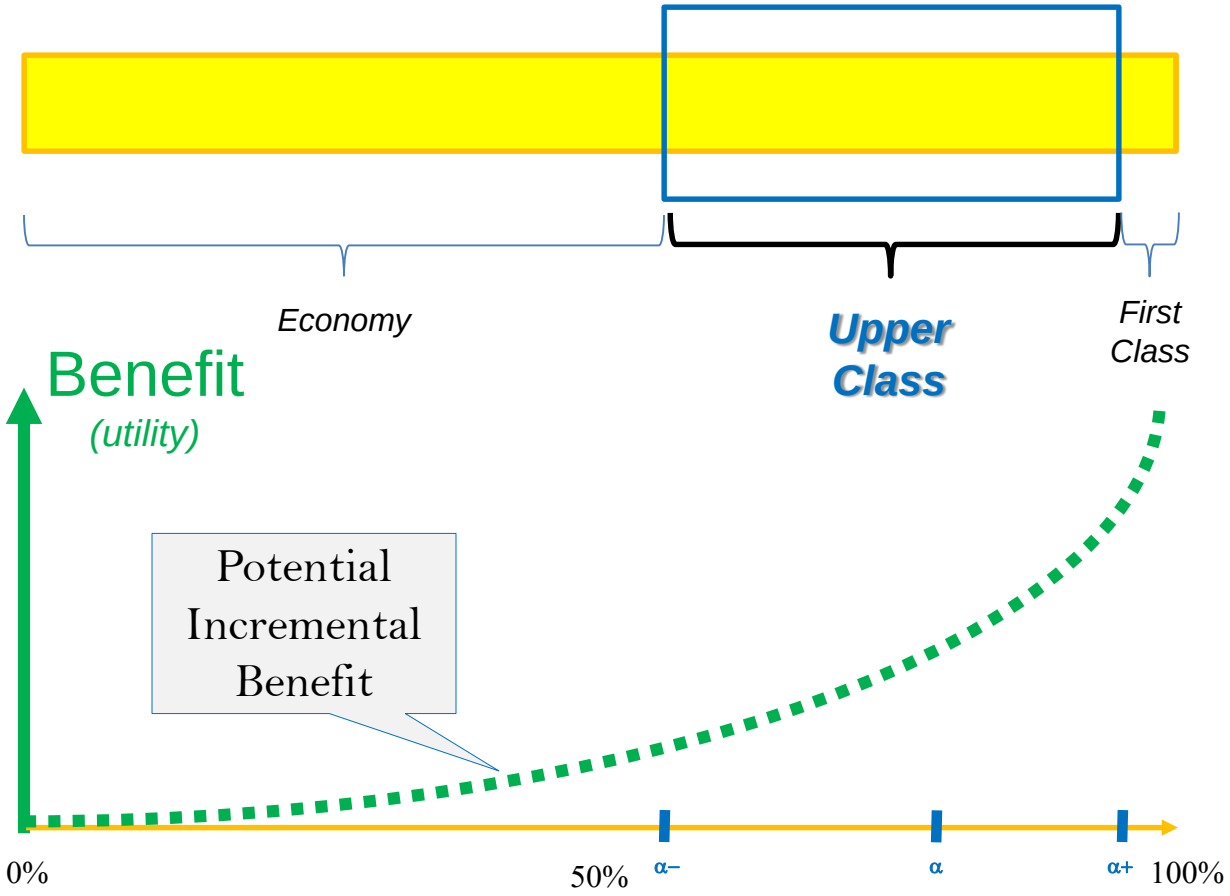

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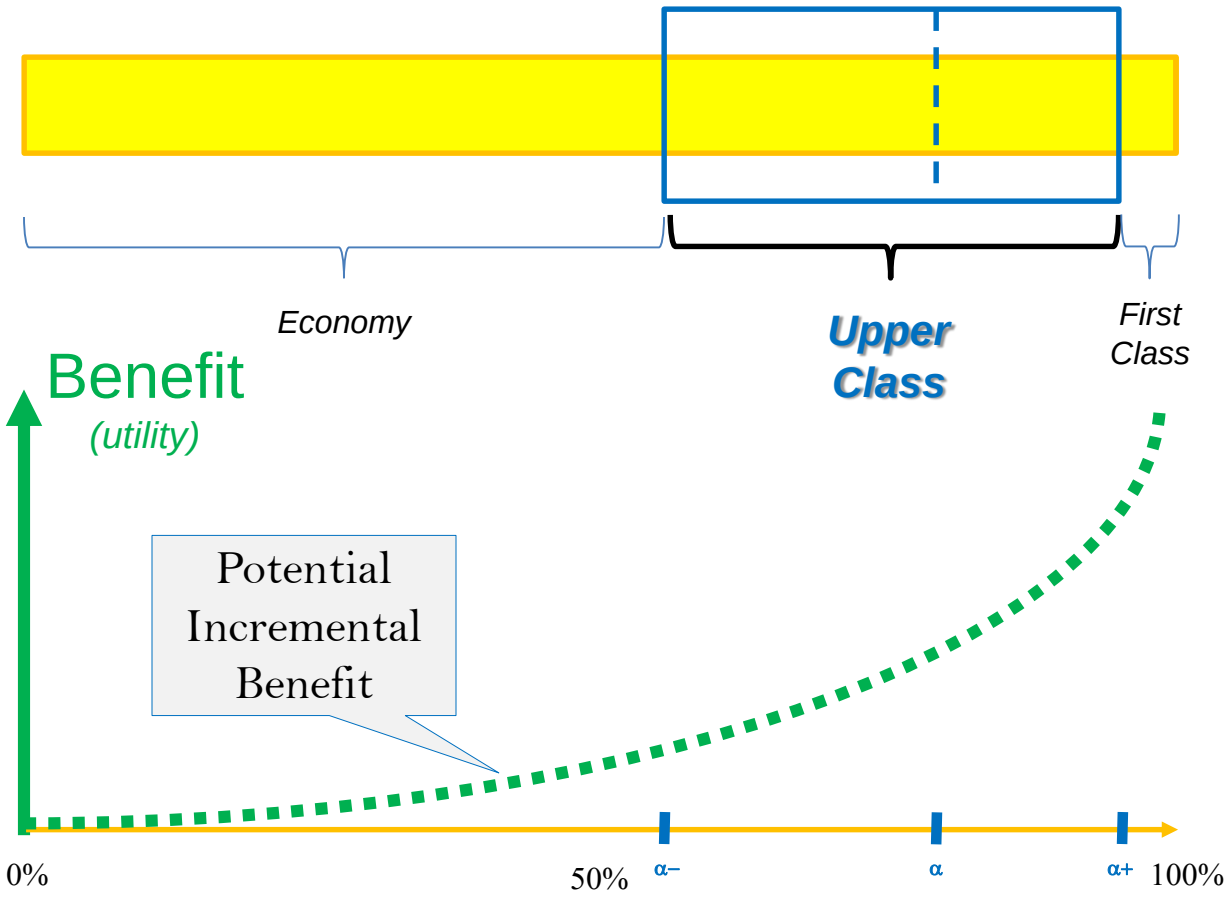

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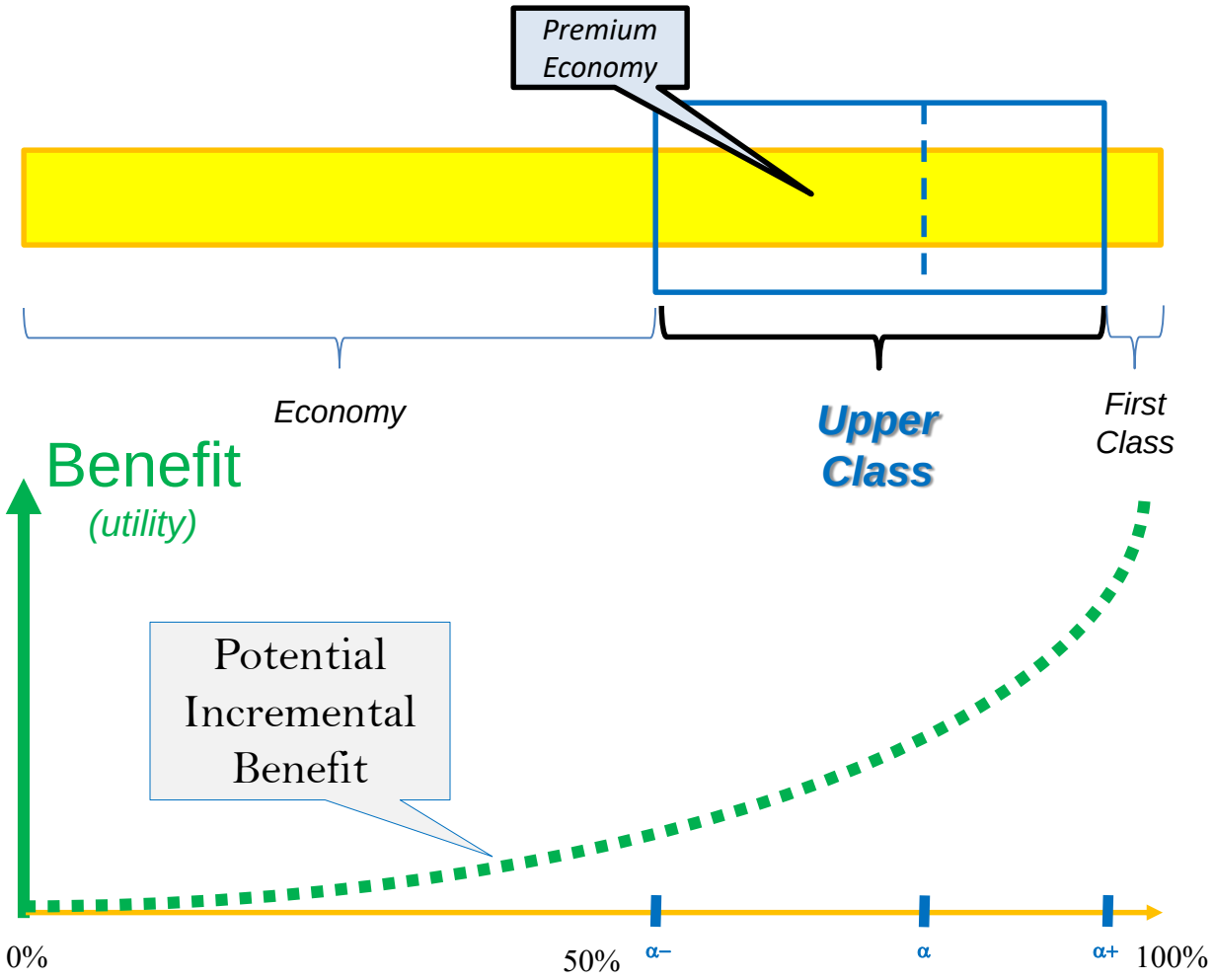

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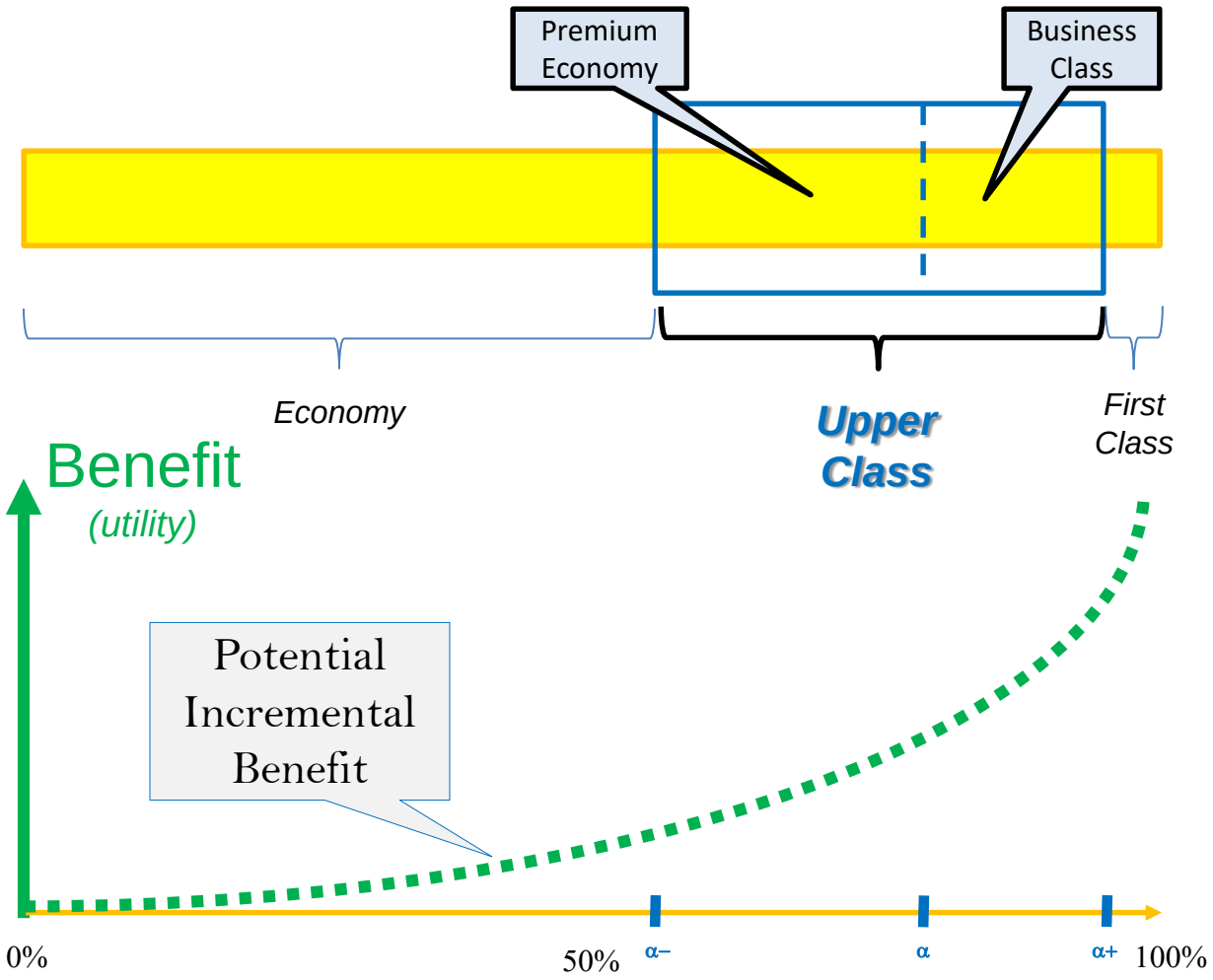

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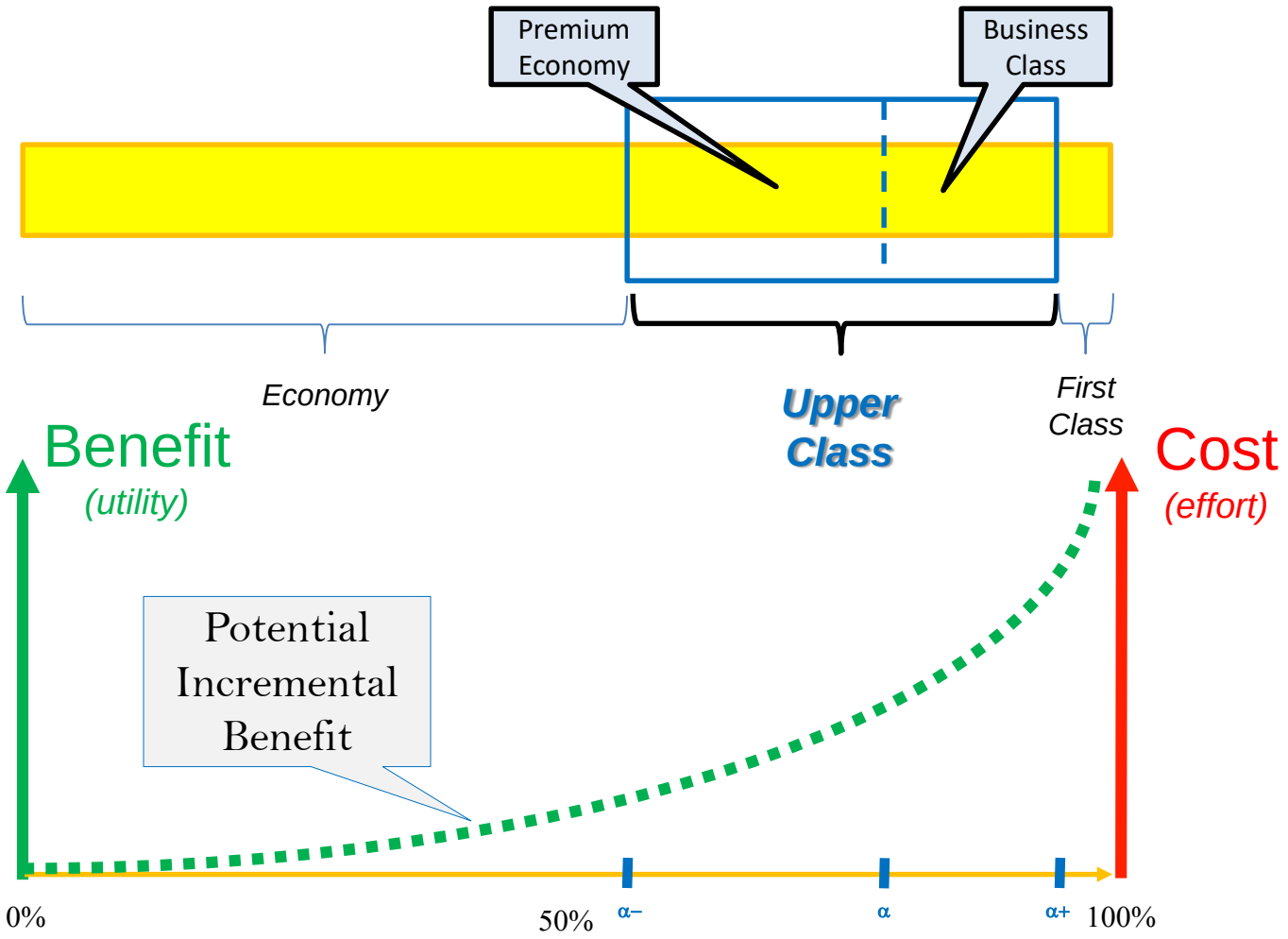

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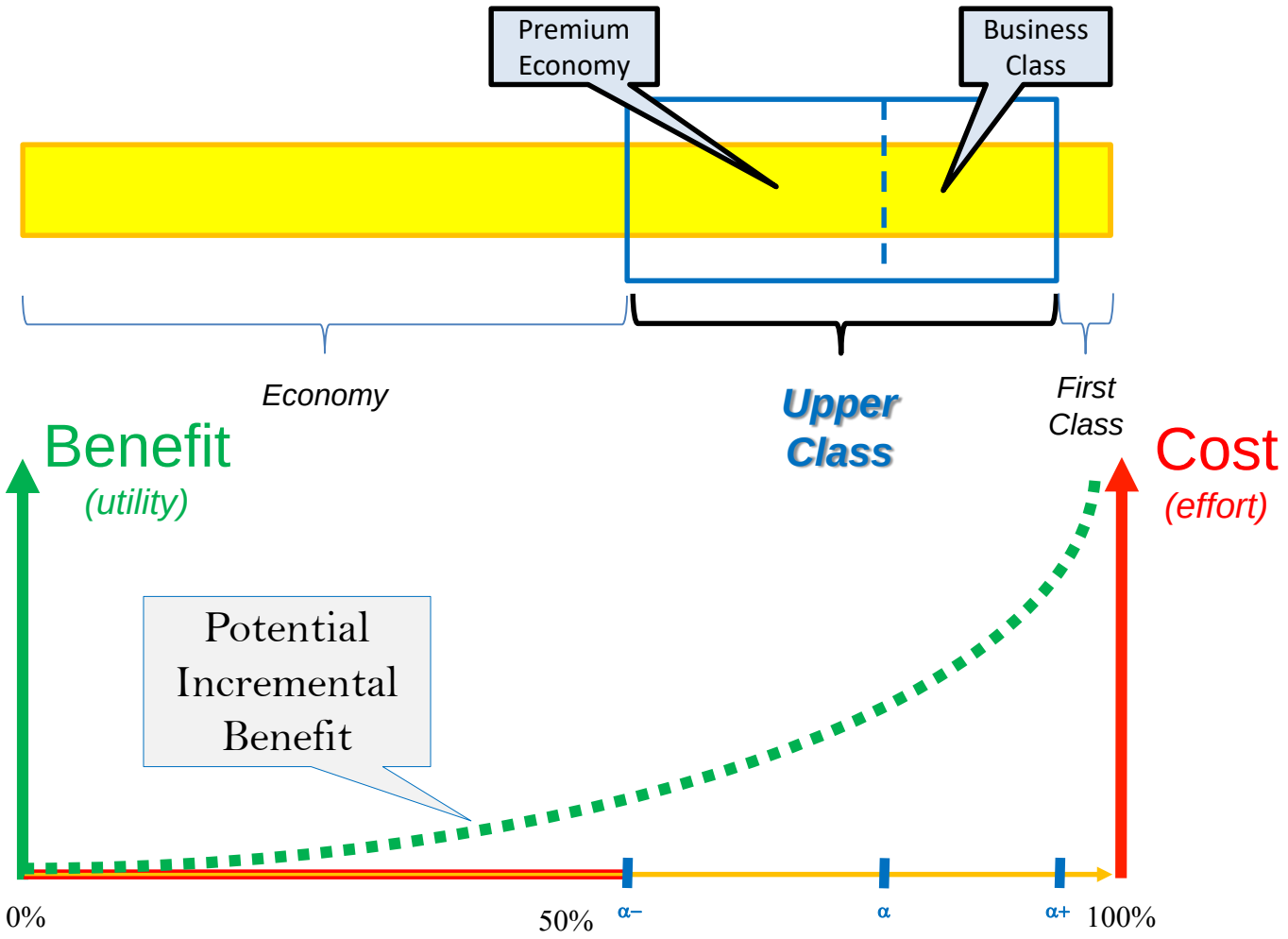

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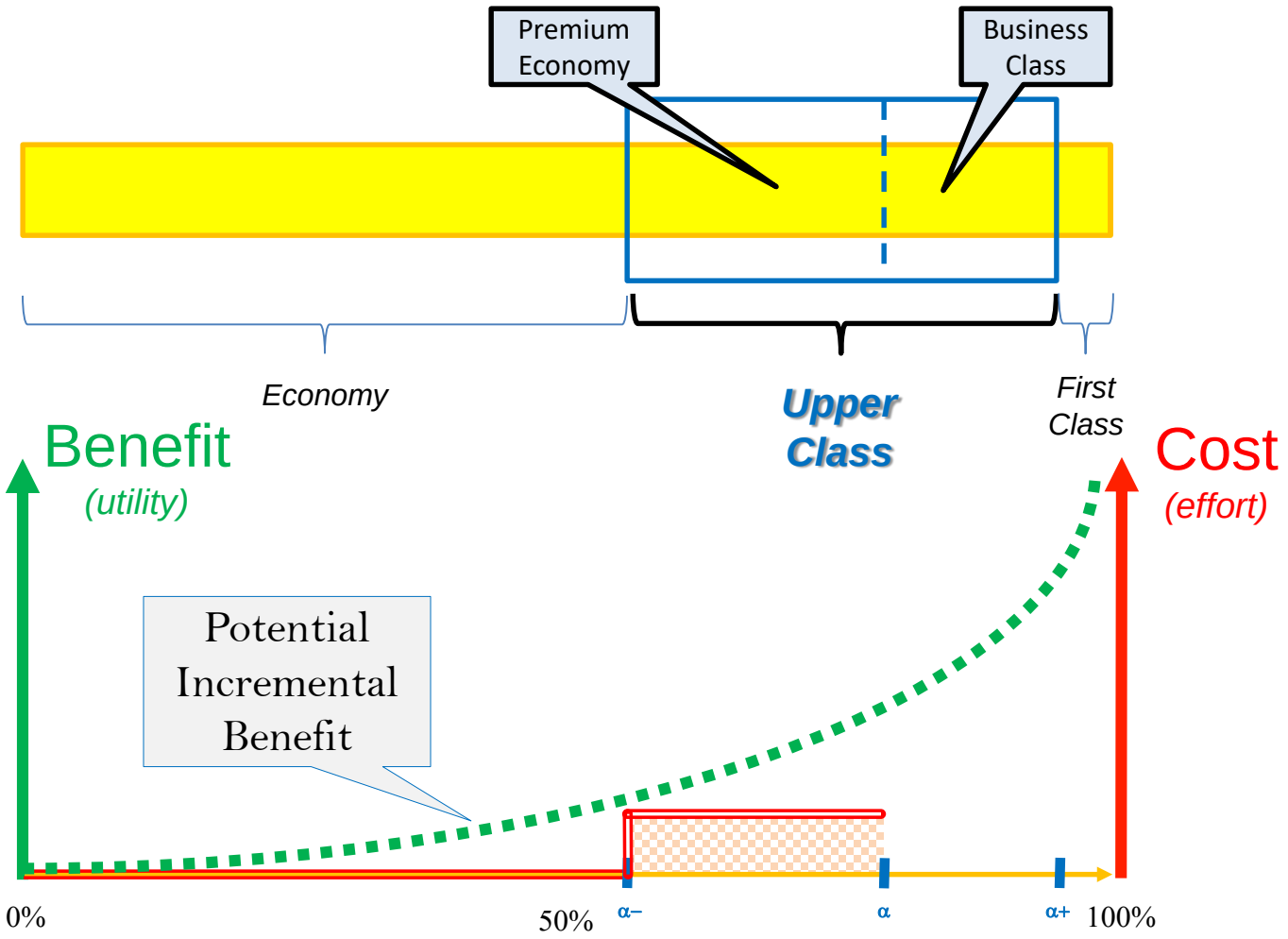

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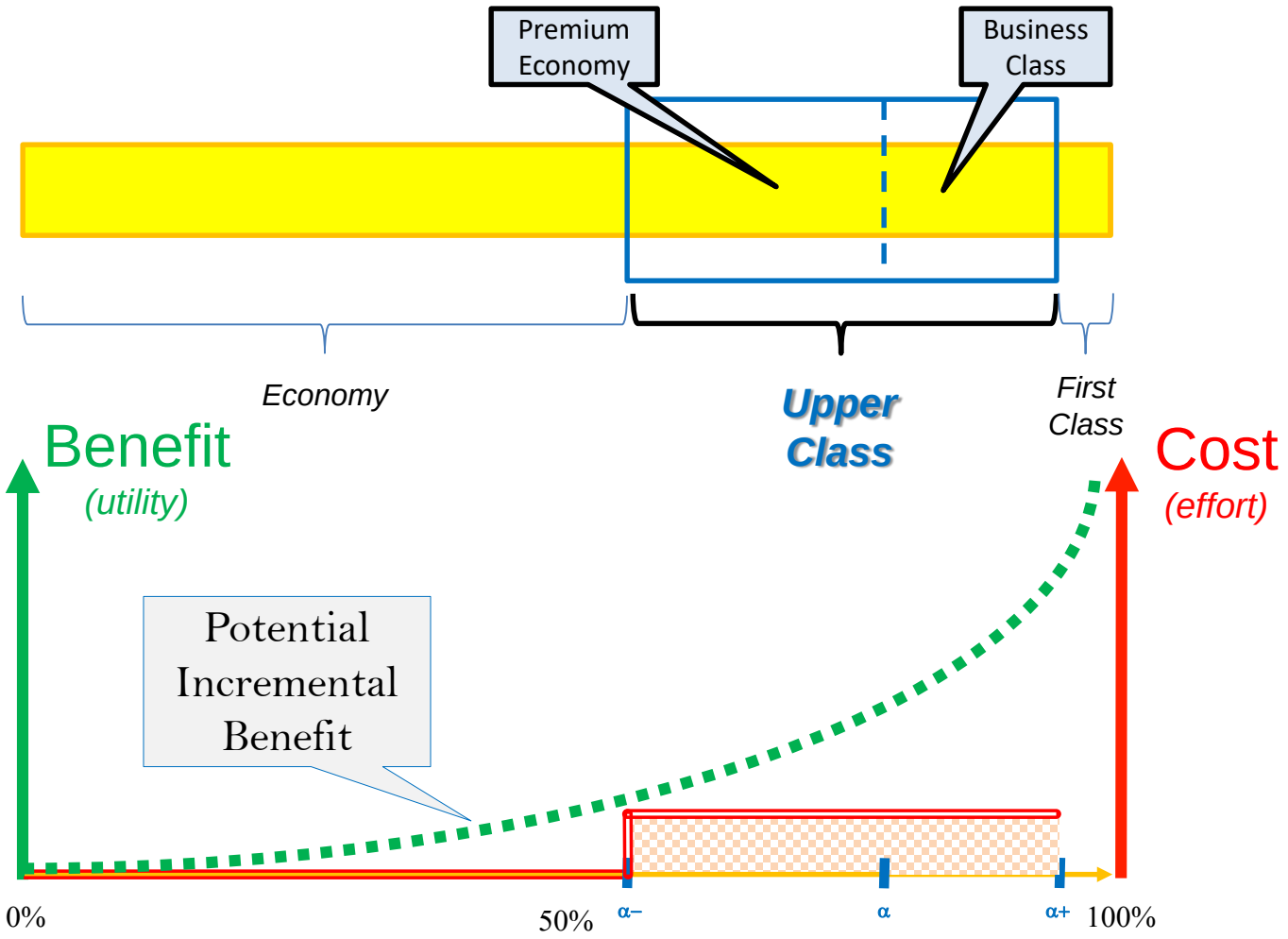

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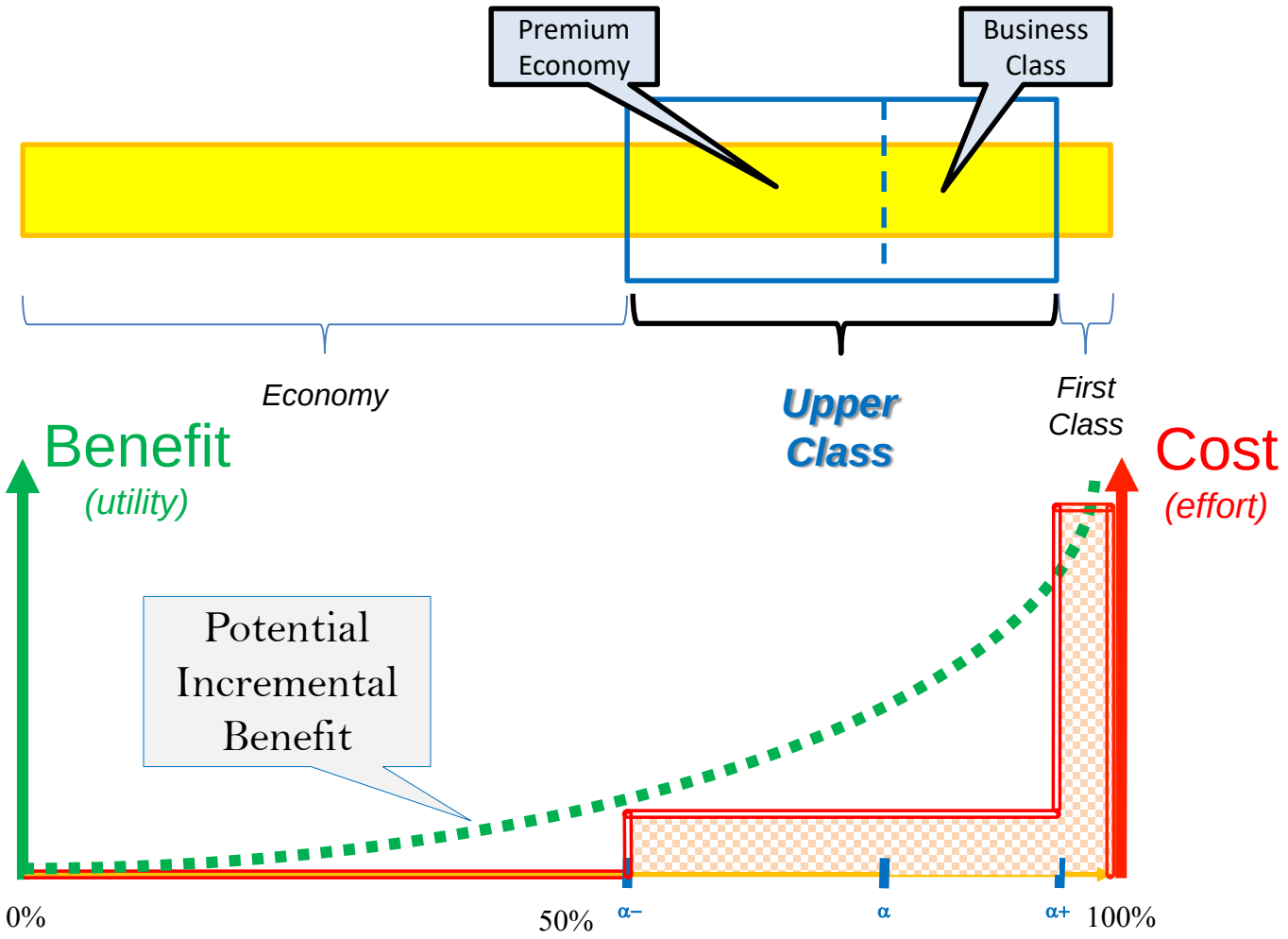

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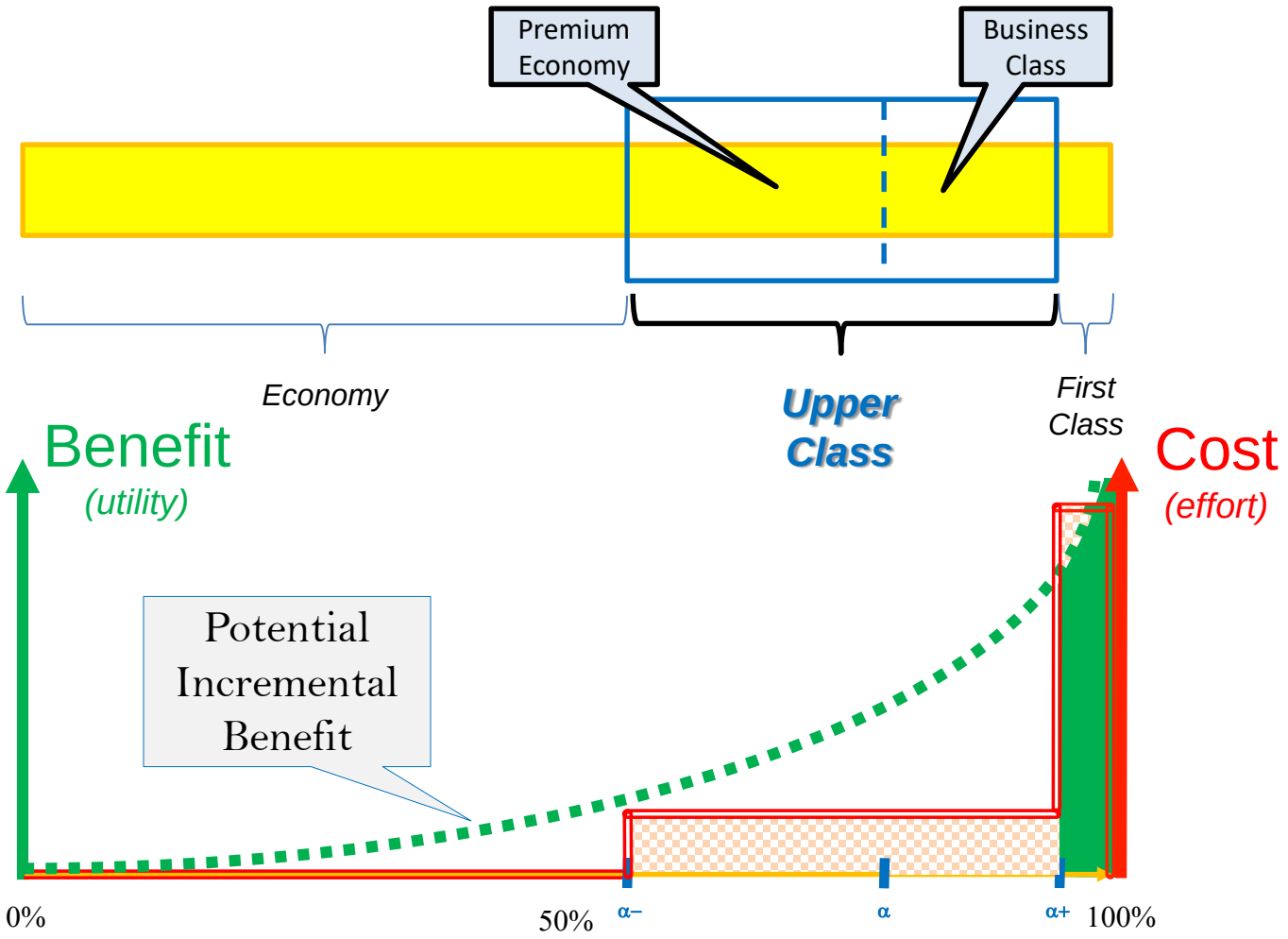

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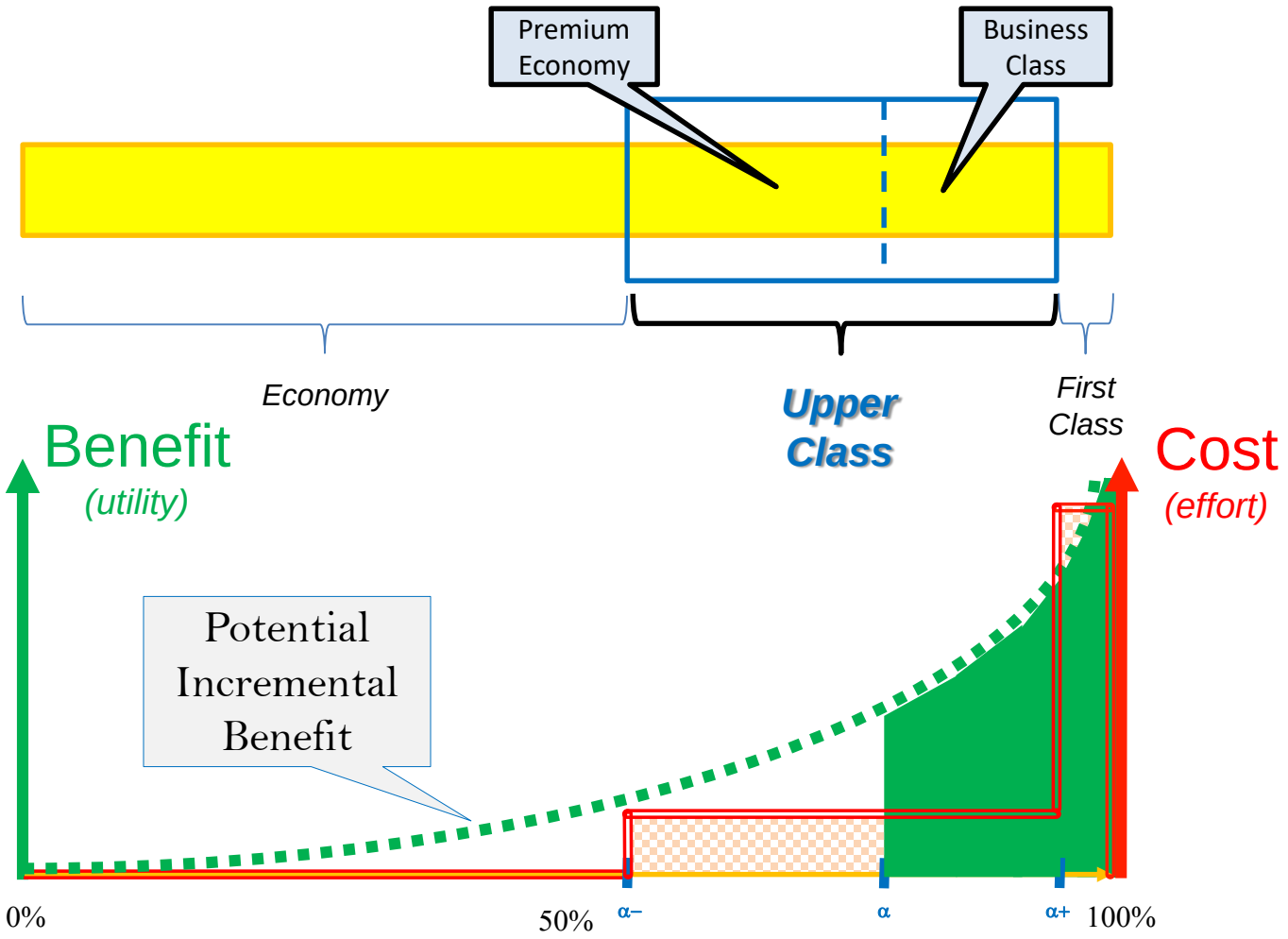

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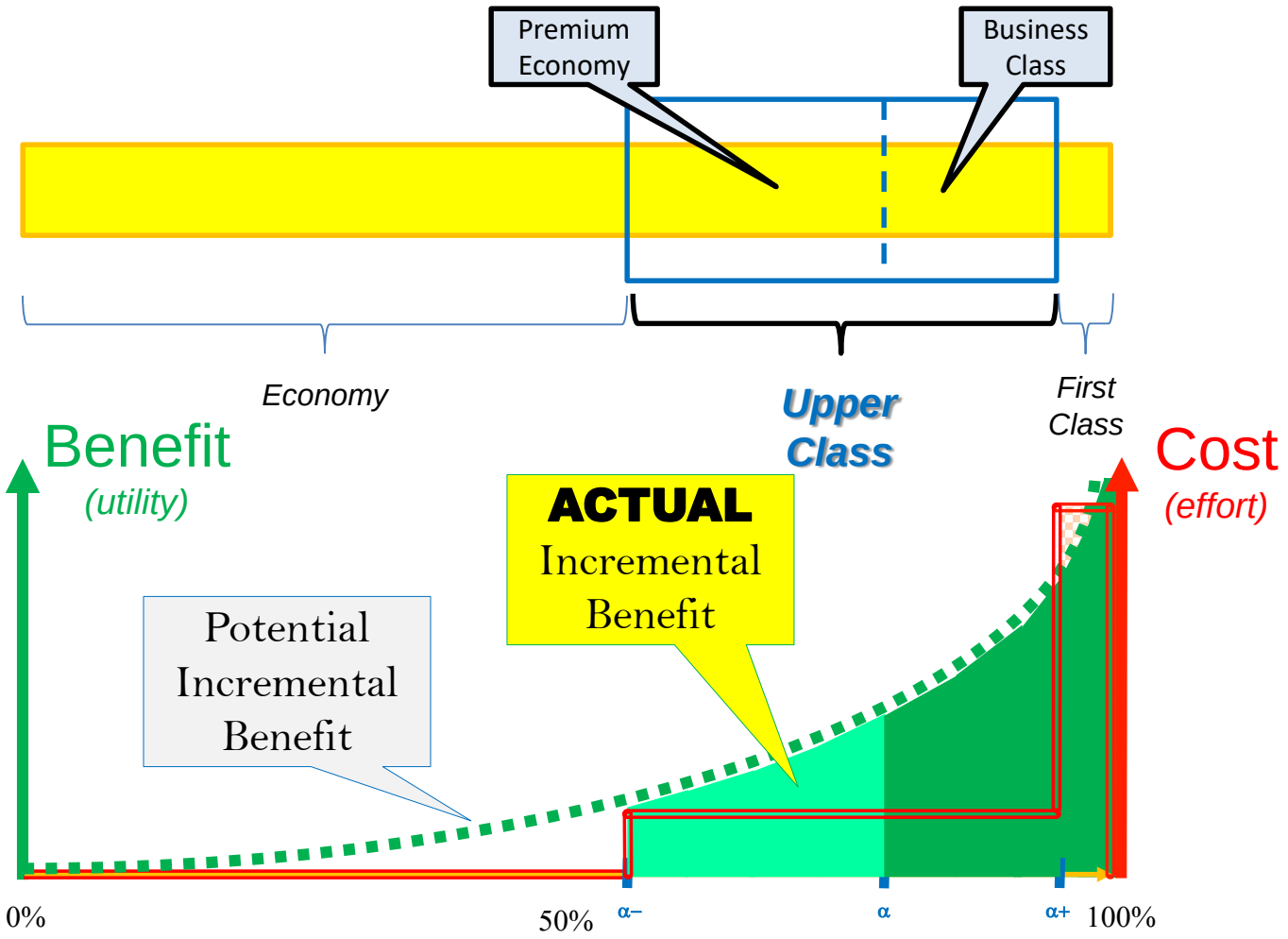

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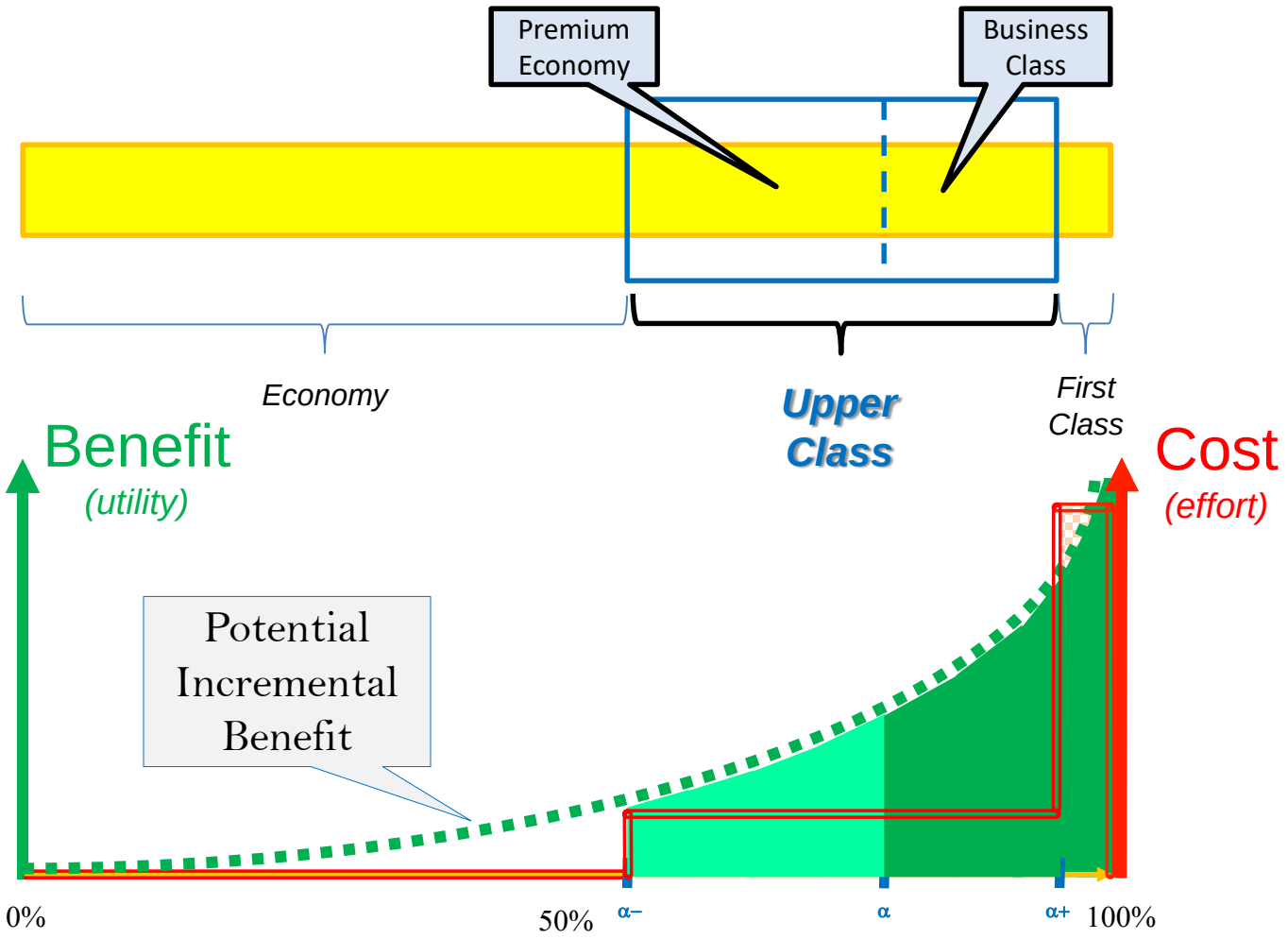

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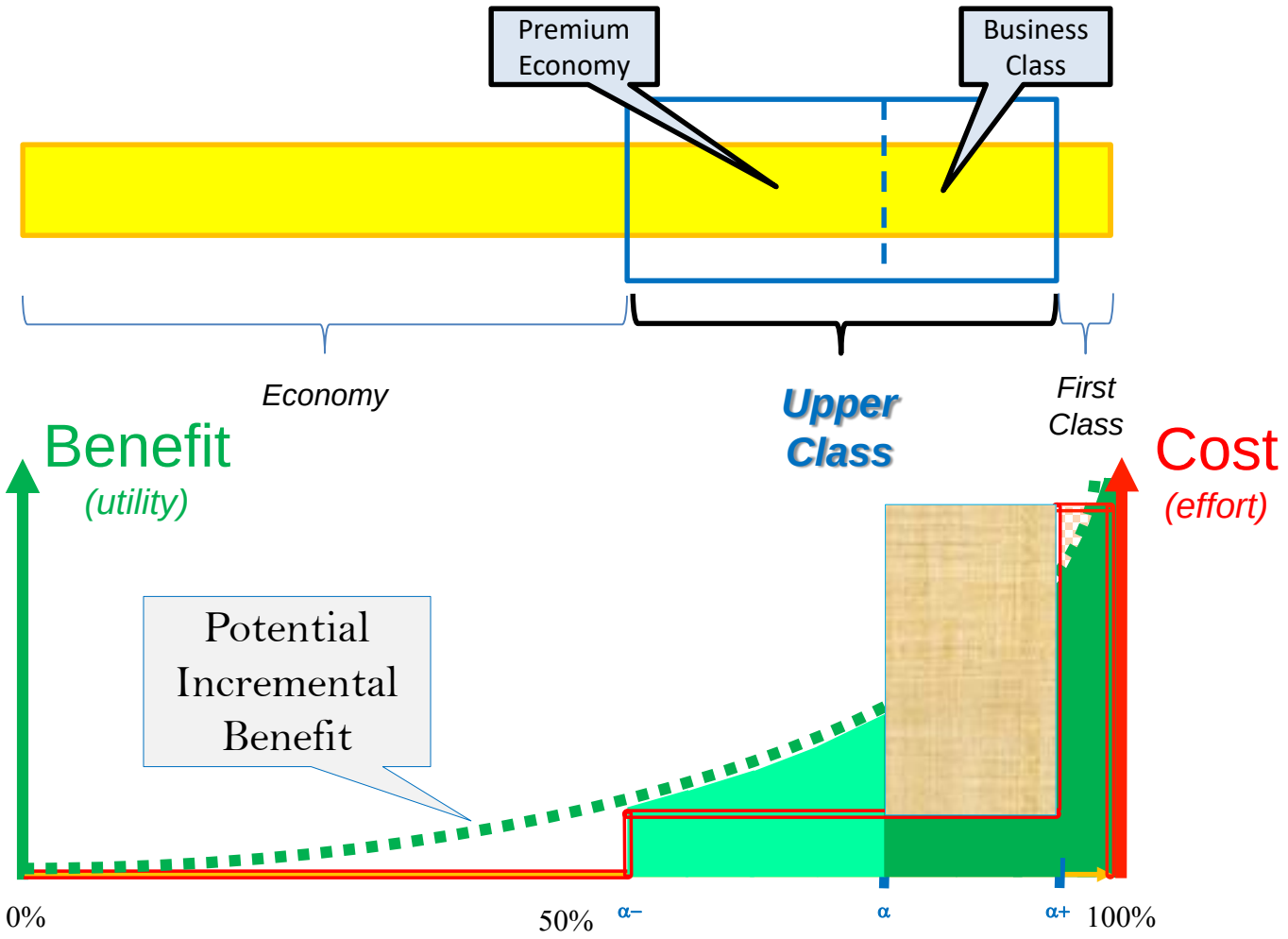

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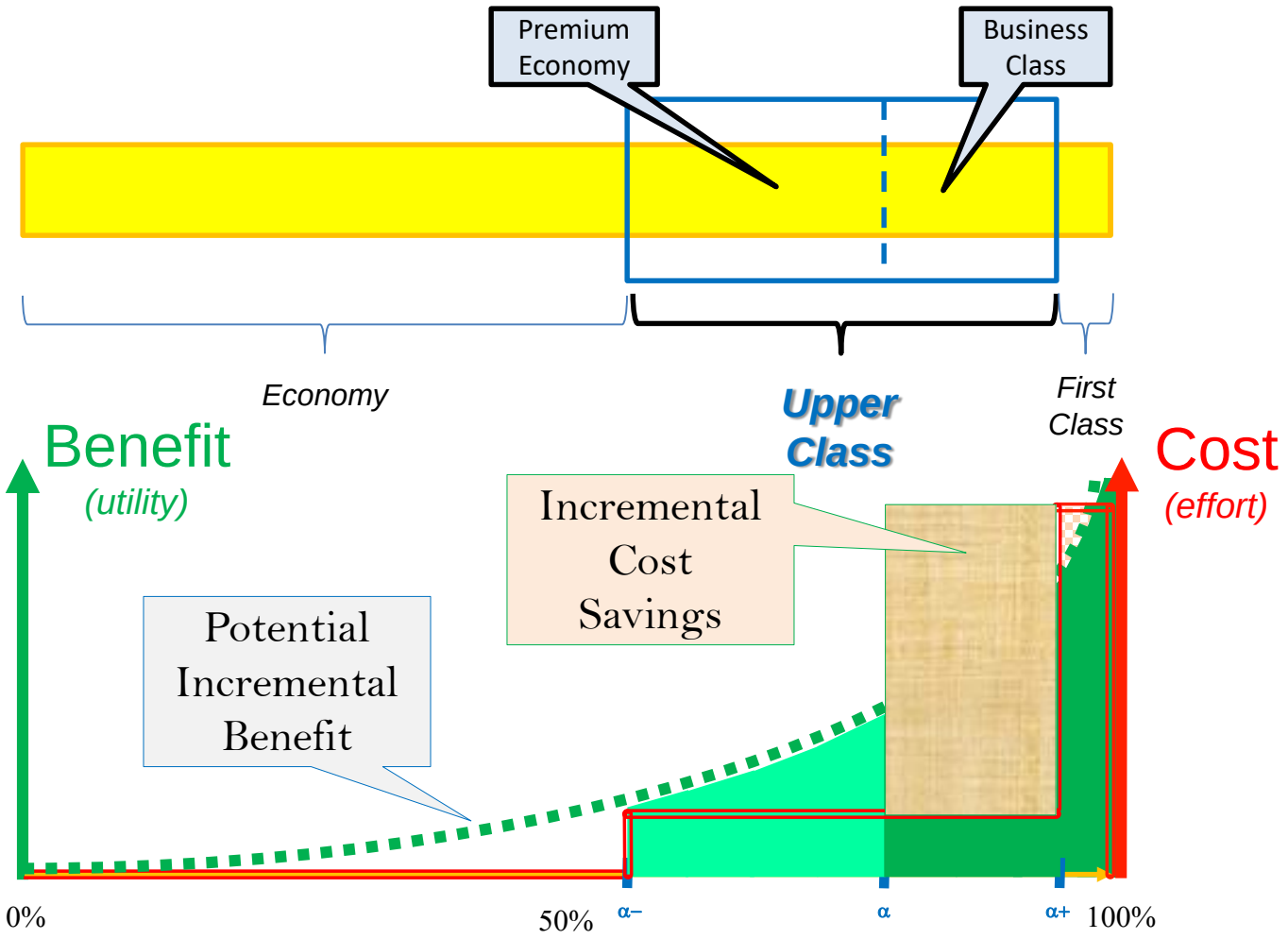

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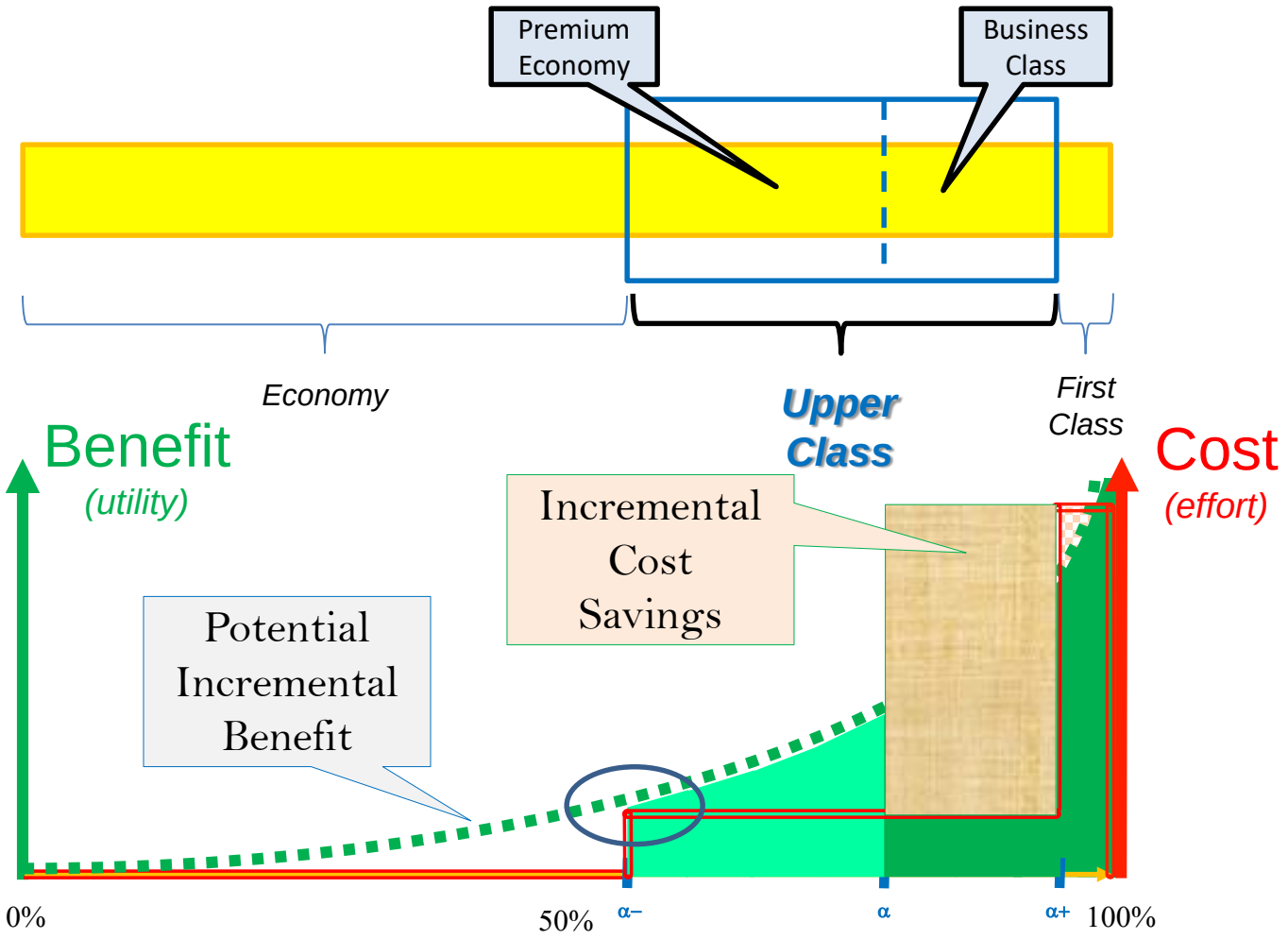

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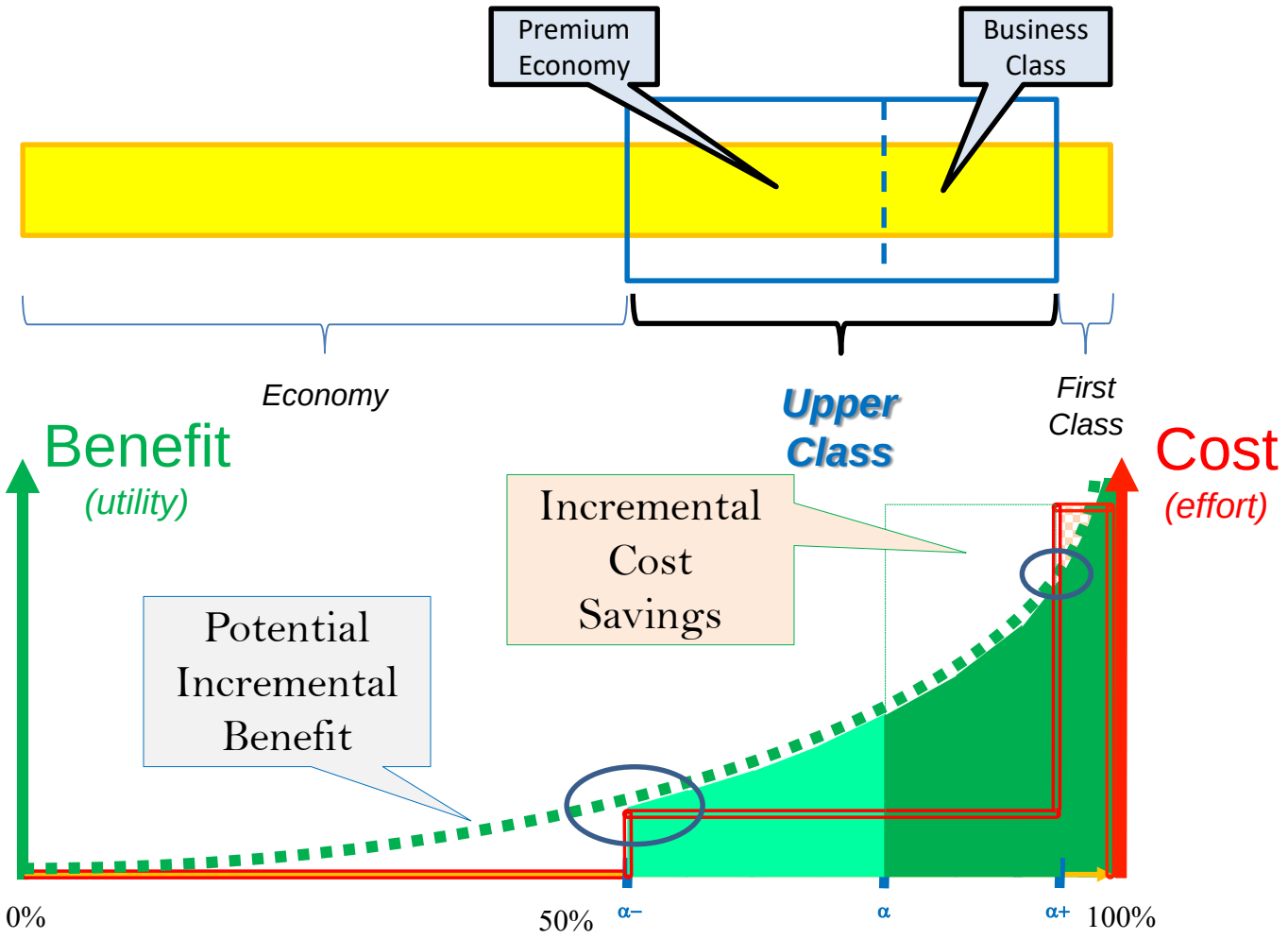

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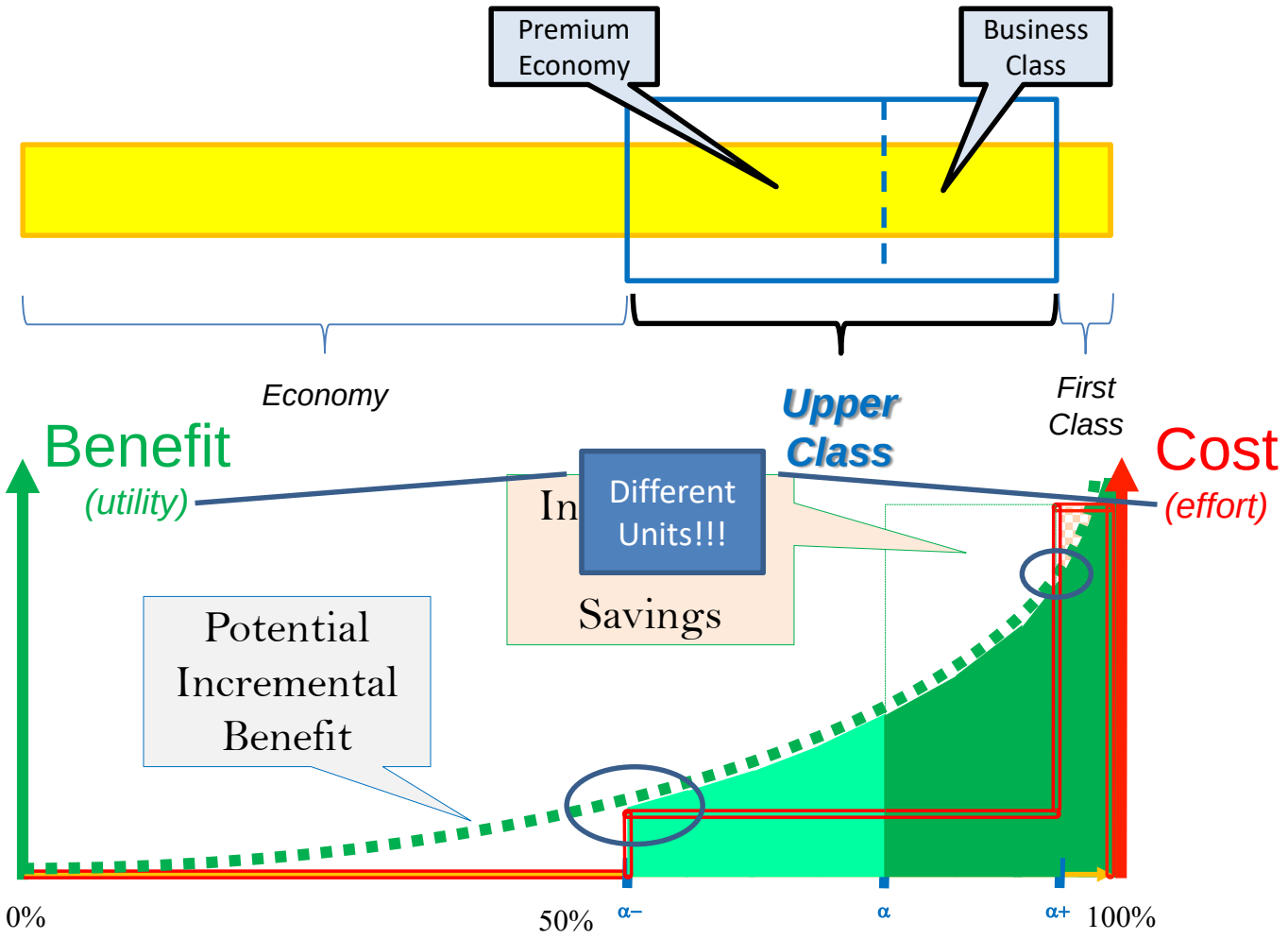

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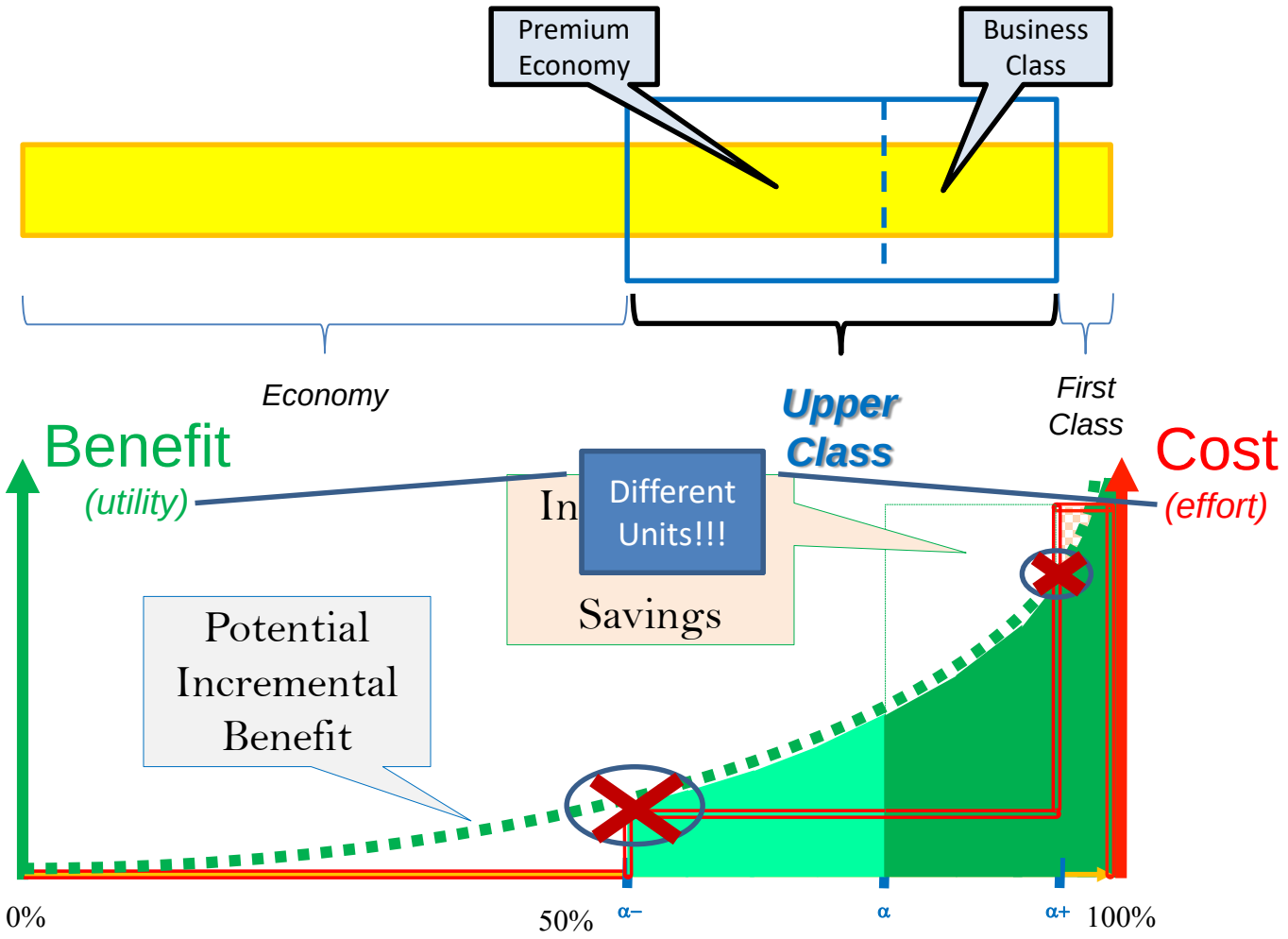

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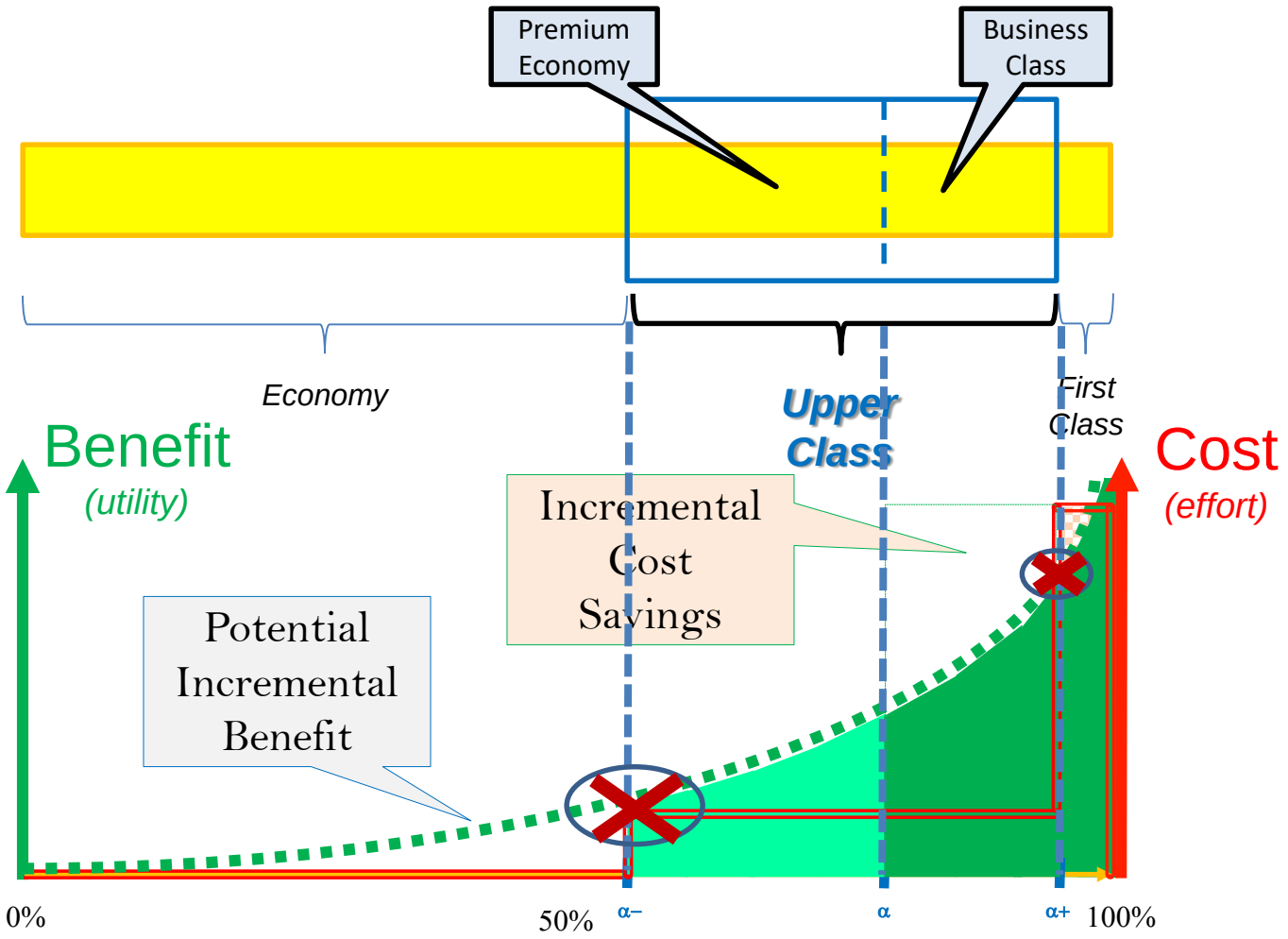

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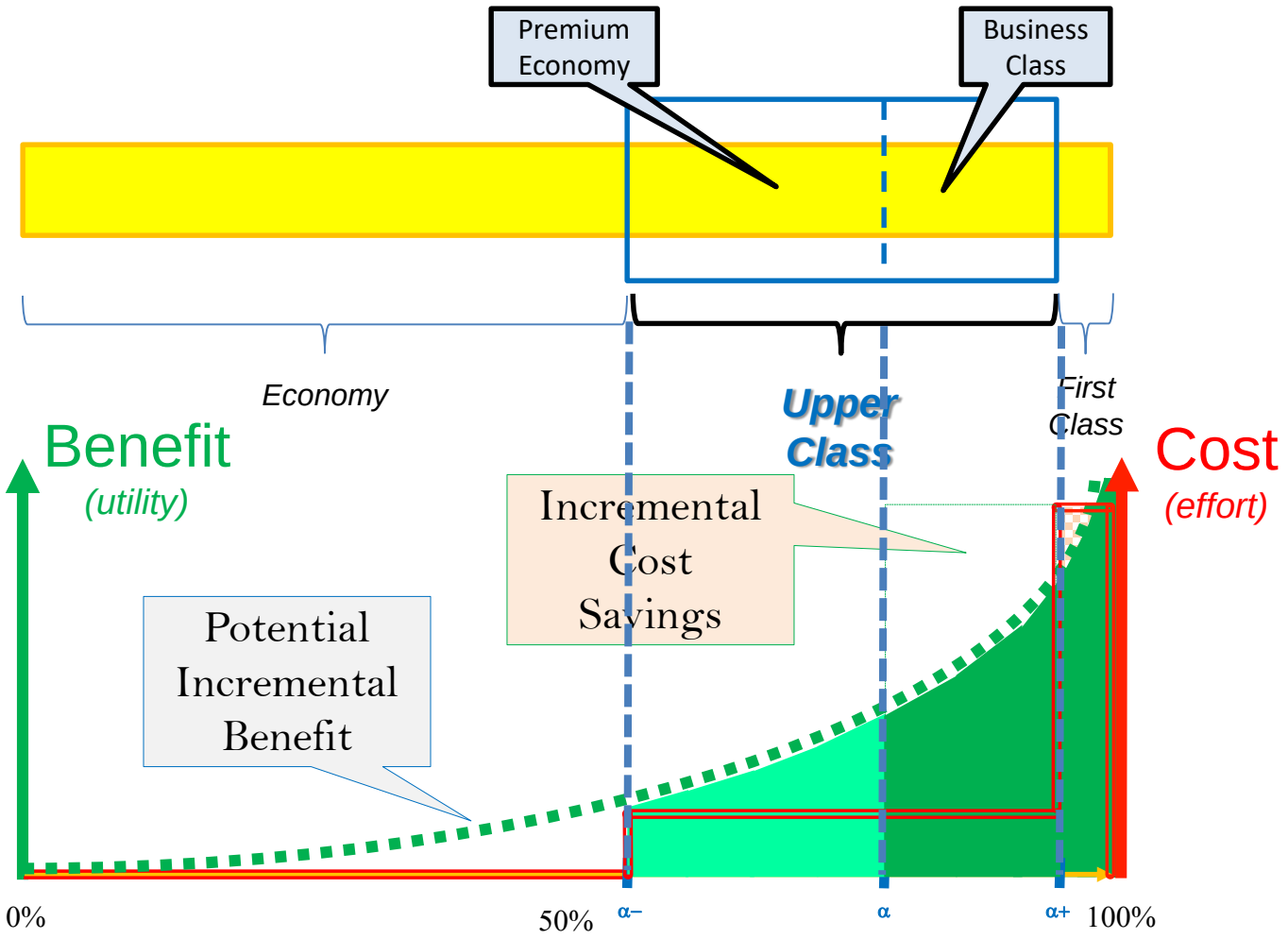

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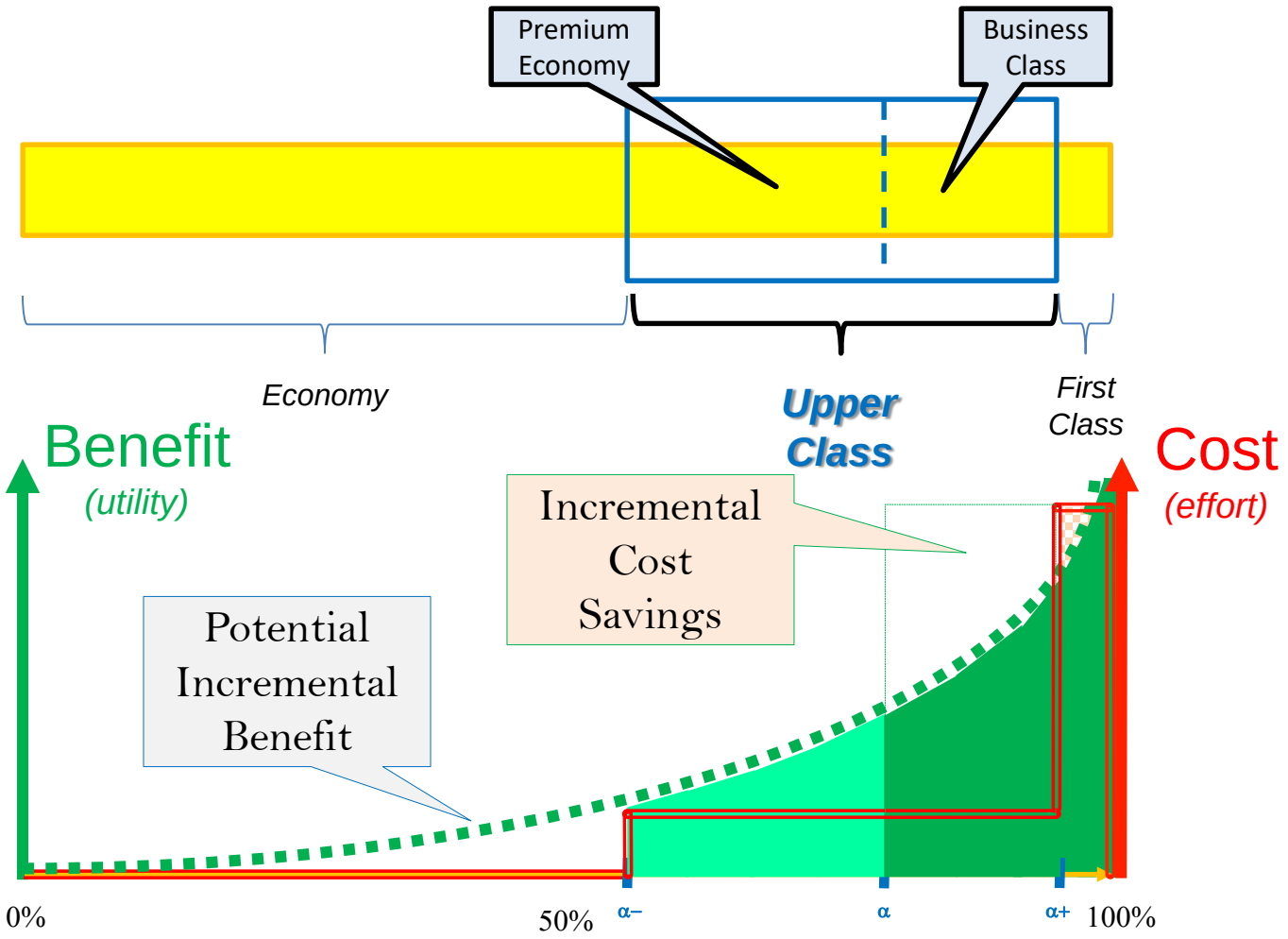

Introduction

Which airline do you think I fly most often?

- Delta Airlines (DA)
- Lufthansa (L)
- United Airlines (UA)
- *American Airlines (AA)*
- British Airways (BA)

Introduction

Which airline do you think I fly most often?

- Delta Airlines (DA)
- Lufthansa (L)
- United Airlines (UA)
- *American Airlines (AA)*[*]
- British Airways (BA)

[*]And I use their *American Advantage (AA)* credit card!

Introduction

Which airline do you think I fly most often?

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- United Airlines (UA)
- *American Airlines (AA)*[*]
- British Airways (BA)

[*]And I use their *American Advantage (AA)* credit card!

(Consider this talk an *AA* meeting)

Client Perspective

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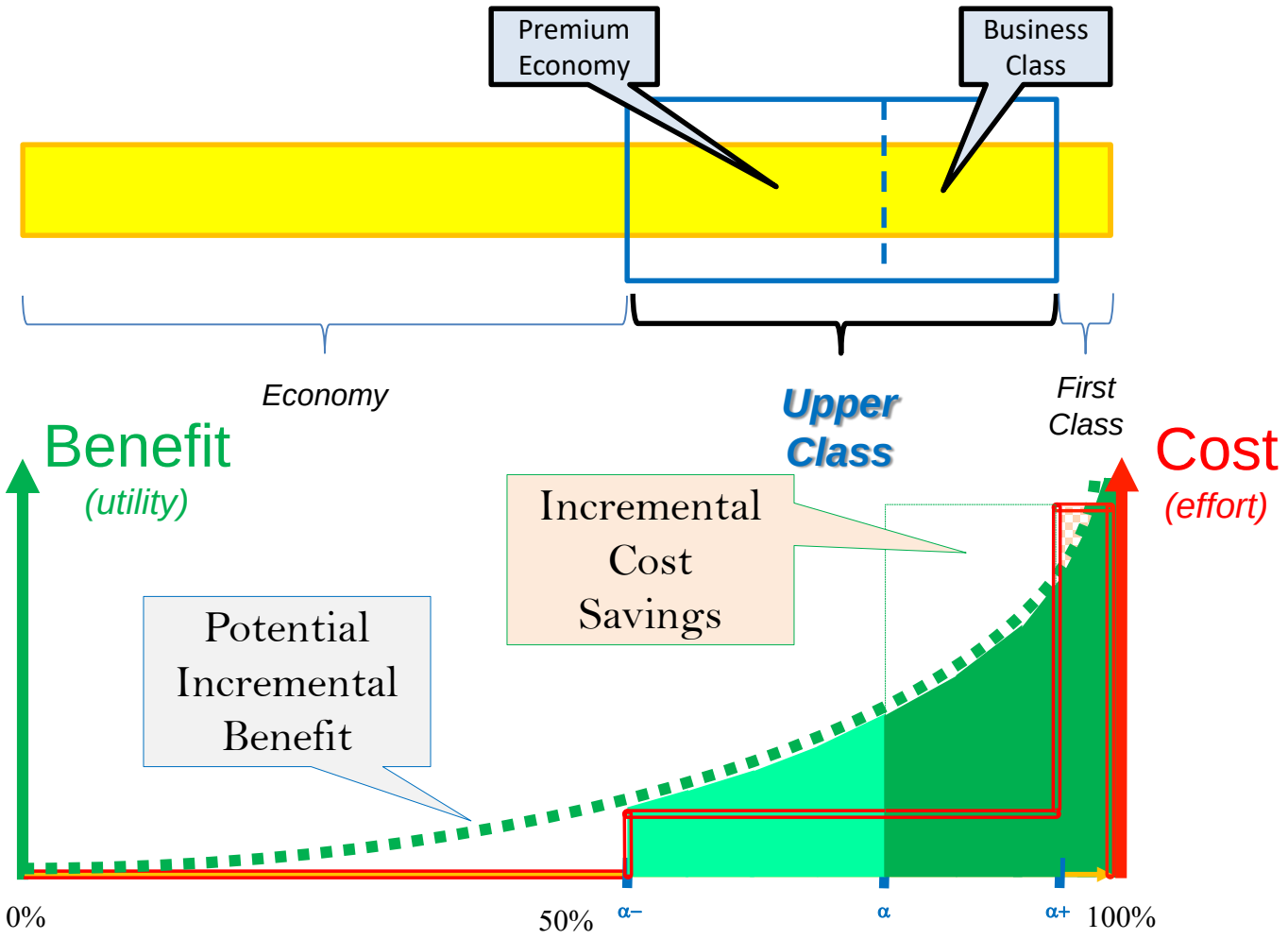
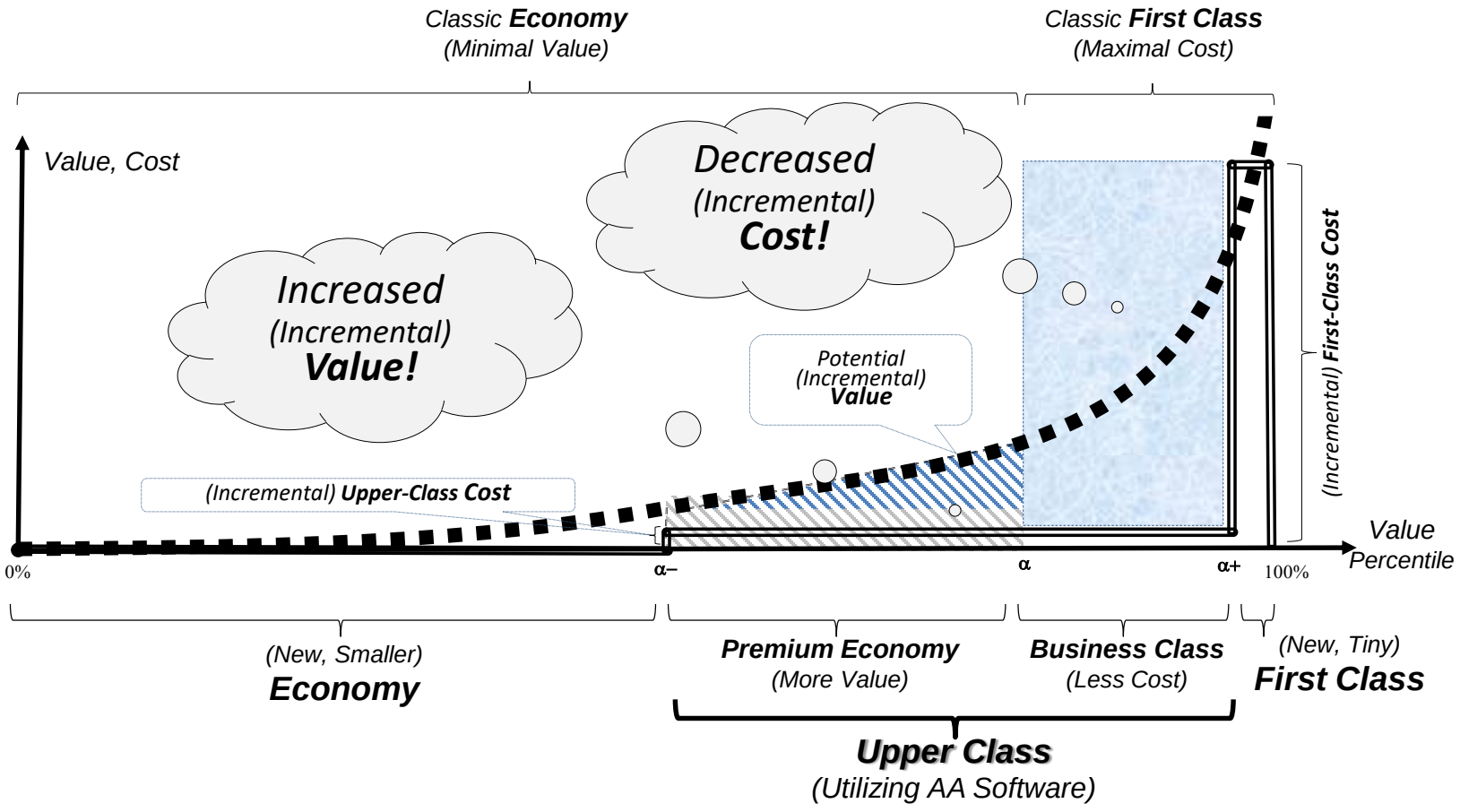


Introduction

Cost/Benefit of Utilizing Allocator-Aware (AA) Software



End of Section

Discussion?

End of Section

Questions?

What Questions Are We Answering?

- Question 0
- Question 1
- Question 2
- Question 3
- Question 4
- Question 5
- Question 6
- Question 7

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Style Alternatives

TIMTOWTDI (Pronounced "*Tim Toady*")

- Three models
  - C++11
  - PMR (a.k.a. C++17)
  - BB20V
- Four interface styles
  - C++11
  - BDE and C++17/PMR
  - BB20V

2. Style for *Allocator-Aware (AA)* Software

C++11-Style [HIGH-COST]

Compile-time centric:

- Pros:
  - Zero overhead (runtime/space): default allocator
  - Allows non-standard addressing: shared memory
- Cons:
  - Forces clients to be templates
  - Raises interoperability issues
  - Complex and difficult (extremely) to implement
  - Not widely used except default; *very* widely disliked

2. Style for *Allocator-Aware (AA)* Software

BDE-Style [MODERATE-COST]

Runtime Centric (Doesn't Invade Object's Type):

- Pros:
  - Client's of *AA* objects need not be templated
  - Enhanced Interoperability (e.g., vocabulary types)
  - Reduced implementation cost (can be automated)
- Cons:
  - Non-zero runtime and spatial overhead
  - Significant implementation and maintenance costs

PMR-style [MODERATE-COST]

PMR-style (a.k.a. C++17 Style)

- Based on same Model as BDE style
- Small syntactic difference:
  - base-class pointer is wrapped in a C++11-style-compliant object
- Expected to supplant BDE-style at Bloomberg
  - E.g., BDE 4.0

2. Style for *Allocator-Aware (AA)* Software

BB20V-style [LOW-COST]

Language support for PMR-style allocators

- Some annotation will denote a class as *AA.*
- Compiler does (almost) all of the "plumbing"...

  … compiler-generated constructors too!
- Allocators are injected independently of the constructor signatures…

  ... vaguely similar to installing a VTAB PTR.

Style Alternatives

No matter what the *AA* style …

- Near same performance as bespoke solutions
- Much lower cost
- Important additional collateral benefits

End of Section

Discussion?

End of Section

Questions?

What Questions Are We Answering?

- Question 0
- Question 1
- Question 2
- Question 3
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- Question 6
- Question 7

Outline

1. Introduction
2. Styles for *Allocator-Aware (AA)* Software
3. Performance Benefits
4. Costs
5. Collateral Benefits
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Considerations

- Performance gains arise from:
  1. Faster allocator/deallocation calls
  2. Improved memory access (locality)
- Which dominates?
  - Short-running programs: *faster allocation calls*
  - Long-running programs: *improved memory access*

Allocation/Deallocation

Common Usage Pattern 1:

- Build up data structures (few or no deletes), access them (briefly), then tear them down.
- ***Monotonic* allocator**:
  - Deallocation is a no-op
  - Memory returned when allocator destroyed
  - Typically used from within a single thread

Allocation/Deallocation

Common Usage Pattern 2:

- Repeatedly allocate/deallocate blocks of a few distinct sizes.
- ***Multipool* allocator**:
  - Dynamically growing pools of fixed-size blocks based on usage
  - Deallocated blocks are retained for re-allocation
  - Two variants: Thread-safe or not

Allocation/Deallocation

Common Usage Pattern 3:

- Need to destroy many objects *en masse,* **and** objects own no resources except memory
- ***Managed* allocator**:
  - Has method that releases all memory for reuse
  - Object destructors are **not** called
  - Supported by both ***monotonic*** and ***multipool***
  - Most local allocators are naturally *managed* ones

Memory Locality

Locality of data in time/space is important.

- Multi-level hardware caching most effective when related data is physically close.
- Long-running programs that repeatedly allocate and deallocate can *diffuse* initially localized data.
- Loss in locality often dominates (“pwnz”) runtime performance of allocate/deallocate.
- Local (arena) allocators attenuate *diffusion*.

3. Performance Benefits

Thread Locality

Local memory allocators facilitate threading

- If distinct threads have their own allocators, synchronization (e.g., using mutexes) can often be avoided or drastically reduced.
- If distinct threads use separate arena allocators, accidental cache-line contention (a.k.a. *destructive interference*, *false sharing*) is naturally avoided.

Maximizing Performance

Achieving maximum performance requires

- Global knowledge of the application
- Solid understanding of different allocator characteristics

3. Performance Benefits

End of Section

Discussion?

End of Section

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Creating and Exploiting *AA*

Two different kinds of costs

1. Up-front costs **creating** (and maintaining) *AA*SI

   E.g., "Plumbing" constructors to propagate user-supplied allocators to all the various subobjects

   - Borne (mostly) by library/infrastructure developers

2. Incremental costs exploiting (or ignoring) *AA*SI

   E.g, Ongoing cognitive burden due to increased interface (and contract) complexity; chance for misuse

   - Borne by many *(most?)* application developers

Up-Front (Library Development) Costs

Converting an allocator-unaware class to *AA*

- For typical* classes, relatively straightforward
  - Add optional trailing allocator to every constructor.
  - Forward the new argument to base classes, data members, and any other managed sub-objects.
  - Denote the type as *AA* using an allocator-trait metafunction.
- *Non-typical classes are more challenging:
  - E.g., Generic, template, and container types

Up-Front (Library Development) Costs

Converting a generic container/template to *AA*

- Template types – e.g., `std::complex`
  - Requires interacting with *AA*-ness of element type
- Container types – e.g., `std::vector`
  - Involves touching methods other than constructors
- Non-allocating templates – e.g., `std::pair`
  - Templated type does not itself allocate memory
- Irregular types – e.g., `std::shared_ptr`
  - Requires domain knowledge of intended purpose

4. Costs

Up-Front (Library Development) Costs

Maintenance burden

- More source code
  - *AA* code is roughly ~10%* [4% – 17%] larger
- More training
  - Learning to write (and properly test) *AA* types
- Opportunity cost
  - Can require a lot of expert library developers' time
  - Other important projects might be delayed

*Measurment made on BDE code base (c 2017).

Up-Front (Library Development) Costs

Mitigating factors

- Readily lends it self to automation
  - `bde_verify`, a currently-available static-analysis tool, catches most common errors.
  - *BB20V* will eliminate *(most?)* manual "plumbing"…
- Developing BB20V technology is itself a substantial one-time up-front cost.
  - Analogous to self-driving car technology… (tbc...)

Incremental (APPLICATION-DEVELOPER) Costs

Typical cost of *using* *AA*SI is comparatively small*

- Much easier/faster than "rolling your own"
  - Simply supply desired allocator at construction
  - Does (of course) require additional testing effort
- No need for custom memory allocation?
  - Ignore *AA* parameters
  - Use *and test* normally
  - Use is entirely "opt in"

*We'll discuss *modern C++ style* later in this talk.

Incremental (APPLICATION-DEVELOPER) Costs

Additional cognitive burden

- Users will still see *AA* features
  - Enlarged (programmatic) interface:

    e.g., Trailing allocator argument in every constructor
  - Enlarged (English) contracts (e.g., for constructors):

    e.g., "Optionally specify a basic allocator to supply..."
- Although the net benefit for those who exploit *AA* clear, the overall net user benefit is less so.

Incremental (Application-Developer) Costs

Additional opportunity for client misuse

- Allowing an object to outlive its allocator
  - [rare] by, say, returning a dynamically allocated object, created using a local (e.g., stack) allocator
- Inappropriate use of special-purpose allocator
  - [common] by, say, repeatedly reusing a monotonic allocator created outside of a long-running loop
- Misuse can be catastrophic or simply fail to improve performance – either way it's a cost!

Incremental (APPLICATION-DEVELOPER) Costs

Incompatibility with some modern C++ features

- *AA* classes require non-trivial CTORs
  - Compiler-generated copy operations won't work
  - Problem is exacerbated by C++11 move variants
  - Aggregate initialization is not currently* available
- The assertion that "*allocators do not interact well with modern C++ move semantics*" is **false!**
  - We will demonstrate why/how later on in this talk.

*The (language-based) BB20V-style eliminates all such syntactic incompatibilities.

Incremental (Application-Developer) Costs

Lifetime management issues

- The (productive) lifetime of an object must not exceed that of its allocator.
  - Requires additional care by application developers
- Limits applicability of certain standard facilities that manage object lifetimes as they neither track nor extend allocator lifetimes.
  - E.g., `std::shared_ptr` and `std::weak_ptr`

Incremental (Application-Developer) Costs

Education, tools, and governance

- Additional administrative costs of *AA* software
  - Proper training (continuing education)
  - Code reviews (by properly trained reviewers)
  - Developer-facing (e.g., static analysis) tools
  - Company-wide policies (on allocator-usage)
- Not atypical of other powerful paradigms
  - E.g., Multithreading, unit testing, and C++ itself!

Creating and Exploiting *AA*

Bottom line

- Real, substantial costs exist
  - [substantial] Up-front library development costs
  - [modest] Incremental application developer costs
- A credible value proposition remains
  - If we don't have (hierarchically) reusable *AA*SI then some application developers *will* need to write it.
  - All the rest will be forced to do without it.

4. Costs

End of Section

Discussion?

End of Section

Questions?

What Questions Are We Answering?

- What is the % of code that benefits allocators?
- Question 1
- Question 2
- Question 3
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5. Collateral Benefits

… but Wait! There's More!

Apart from frequent (and sometimes dramatic) performance gains…

- …investing in an *AA*SI provides other benefits
  - rapid prototyping; modularity; (hierarchical) reuse; testing; instrumentation; object placement
- Investment in ultra-performance-tuned, "one-off" data structures are unlikely to provide any of these valuable ***collateral benefits***.

5. Collateral Benefits

Rapid Prototyping, and Predictability

- Design with AA is low-cost and low-risk.
  1. Select from suite of existing allocation algorithms.
  2. Plug into *AA*SI components in application.
  3. Measure!
  4. Tune.
  5. Repeat, as needed.
- **Deploy immediately!**

5. Collateral Benefits

Rapid Prototyping, and Predictability

- Design with AA is low-cost and low-risk.
  1. Select from suite of existing allocation algorithms.
  2. Plug into *AA*SI components in application.
  3. Measure!
  4. Tune.
  5. Repeat, as needed.
- Deploy immediately! And/or **use as proof-of-concept for custom-data-structure project!**

Modularity and Composition (Reuse)

The BDE-style allocators are *chainable*.

- I.e., One allocator provides some functionality, then goes to its *backing* allocator when additional memory is needed.
- Examples:
  - A “small block” allocator can “fall back” on a “large block” one for big memory chunks as needed.
  - One allocator provides some features (e.g. metrics gathering) and “falls back” to another for memory.

Testing and Instrumentation

Testing: `bslma::TestAllocator`

- Check for memory leaks
  - Log allocate/deallocate calls
  - Match deallocations with known allocations
- Test exception safety
  - Throw **`bsl::bad_alloc`** on cue in tests
- Test for memory-range overwrites (sentinels)
- Non-invasive
  - Works on arbitrarily large-scale code

Testing and Instrumentation

Instrumentation: *Tagged Allocator Store (TAS)*

- Monitor memory usage on an object basis
  - Leverages `bslma::Allocator` vocabulary type
  - Multiply inherits `gtkma::AllocatorStore`
  - Uses `dynamic_cast` to "opt in" to reporting
- Strictly better than other solutions
  - "Opt In" is fine-grained and entirely optional
  - Provides object- as opposed to class-based info
  - Works on arbitrarily large-scale code

Whole-Object Placement

Placement of objects in memory is important!

- Allocators facilitate the placement of (entire) objects in “special” memory.
  - (placement `new` is for only the top-level footprint)
- Examples
  - High-bandwidth memory (HBM)
  - Hardware protected (no read and/or write access)
  - Persistent or file-mapped (**`mmap`**) memory
    - The `gmalloc` allocator is but one relevant example

5. Collateral Benefits

Garbage Collection

Sometimes we need to get down to the metal

- Traditional use of managed pointers can be unnecessarily expensive in both time and space.
- Large (many-node) data structures built out of ***raw pointers*** can be summarily "winked out"!
  - The release method of a (managed) allocator will unilaterally reclaims all memory (*w/o destructors).*
  - **Requirement**: The data structures own no resources other than memory from that allocator.

5. Collateral Benefits

Pluggable Customization

The utility of an *AA*SI for realizing performance and other, collateral benefits are open-ended.

- Most (but not all) of these benefits depend largely (albeit indirectly) on the ability to inject allocators into a system ***at runtime.***
- Without having invested in an *AA*SI, the cost of pursuing such benefits would require prohibitive expenditure of time and effort – especially w.r.t. to bespoke data structures.

5. Collateral Benefits

End of Section

Discussion?

5. Collateral Benefits

End of Section

Questions?

What Questions Are We Answering?

- With use of smart pointer, do we need to test?
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- Question 2
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Why the Quotes?

Classical allocators specifications have sucked!

- C++98 allocators didn’t work at all!
  - stateless (and completely useless) – Lakos’96
- C++03 allocators had “weasel words”
  - Not portable: allowed but not required to work
- C++11 allocators are a pain in the @SS!
  - Hard to write; invade object type; *very* hard to use
- C++17 allocators are much better
  - Runtime polymorphic; **much** easier to write/use

Why the Quotes?

People *invent* “reasons” for *not* liking allocators

- State-of-the-art allocators are as good or better
- PMR violates the zero-overhead principle (ZOP)
- (Generally) poor *runtime performance* trade-off
- (Unmanageable) verification/testing complexity
- (Gross) incompatibility with modern C++ style
- Don’t play nice w/modern C++ move semantics
- *Object pools* and *factories* are as good or better

6. “Concerns”

State-of-the-Art Global Allocators

“Advances in global memory allocators have led to dramatic performance improvements – especially with respect to real-world multithreaded applications; wouldn’t replacing the compiler-supplied global memory allocator with a newer, “state-of-the-art” one achieve most (if not all) of the real benefits derived from assiduous use of local allocators designed into a program?”

6. “Concerns”

State-of-the-Art Global Allocators

Global allocators are not (cannot be) sufficient.

- General-purpose global allocators are ignorant of application-specific details.
- They cannot achieve the locality that local allocators can.
- They cannot not provide the collateral benefits.

Zero-Overhead-Principle Compliance

“For all but the C++11 model, *AA* objects (1) require maintaining extra state – even for the most common case (i.e., where the default allocator is used) – and (2) necessarily employ virtual-function dispatch when allocating and deallocating memory; isn’t that too inefficient for *AA* software to be viable in C++?”

6. “Concerns”

Zero-Overhead-Principle Compliance

Neither *letter* nor *spirit* of ZOP is violated.

- The needed “extra space” can be addressed
  - Used only upon allocation
  - Stored outside the footprint
  - Elided in common case(s) especially the default
- The virtual-function dispatch “overhead”
  - Can be bound *at compile time* in relevant cases
  - Is invariably negligible compared to added locality
  - Is generally a red herring: allocators boost runtime

Zero-Overhead-Principle Compliance

AA software makes prudent design trade-offs

1. Benefits to some with negligible cost to others
   – Implementation change: O(N) -> O(log N)
2. Solid benefits for a few but small cost to other
   – **`std::list<T>::size()`** must be O(1)
3. Large benefit for expected case but significate cost for others
   – Short-string optimization (SSO)
     - Especially costly for (sparse) vectors of string data

Zero-Overhead-Principle Compliance

AA software makes **these** design trade-offs

1. **Benefits to some with negligible cost to others**
   - Implementation change: O(N) -> O(log N)
2. **Solid benefits for a few but small cost to others**
   - `std::list<T>::size()` must be O(1)

Allocator Tax Analogy

Everyone must buy auto insurance:

Accidents are *unusual* – but not ***rare!***

6. “Concerns”

Verification/Testing Complexity

“Failure to properly annotate types or propagate allocators can undermine the effectiveness of the allocation strategy and can lead to memory leaks, especially when ‘winking out’ memory; aren't the extensive verification, testing, and/or peer review required to avoid such errors impracticable?”

6. “Concerns”

Verification/Testing Complexity

Almost every new library or language feature has a learning curve and requires additional testing.

- Allocators are entirely opt-in (can ignore them)
- Special-purpose allocators do require training
- “Winking out” is inherently for experts only
- Static analysis tools (e.g., `bde_verify`) can help
- `bslma::TestAllocator` (e.g., leak testing)
- BB20V-styled *will* help dramatically!

6. “Concerns”

Compatibility with Modern C++ Style

“C++11 encourages a style of programming where objects are more often passed and returned by value, sometimes relying on rvalue references to move these objects efficiently whereas BDE style relies on passing *AA* objects (by address) as arguments to achieve optimal efficiency and control over the allocator employed; isn't this ‘old-fashioned’ style unjustifiably restrictive?”

Compatibility with Modern C++ Style

Custom allocators do not affect function style

- Returning by value is inherently inefficient
  - The retuned object must be constructed each time
  - Supplying an allocator doesn’t help
- Returning an object by argument is faster
  - Can reuse object to return multiple values
    - E.g., Accumulator Pattern: *tokenizer returning strings*
  - Full control over result allocator in client context
  - Can build returning style on top (but not vice versa)

Move vs. Allocate

“When two objects use different allocators, *move* assignment degenerates to a copy operation and *swap* becomes undefined behavior; doesn’t that imply that local allocators should be avoided to enable such operations?”

Move vs. Allocate

Move assignment is often *not* as efficient as copy!

- Object returned by value are *not* moved
  - They are constructed in place via RVO (or NRVO)
- Moving objects around “mucks” with memory
  i. Locality (cache-lines, caches, pages, etc.)
  ii. Constructive interference (a.k.a. “true sharing”)
  iii. Prefetching
  iv. Optimal N-way-cache/main-memory-bank access
- Moving within a container (or an “arena”) is OK
  - Preserves i and ii (above) but *not necessarily* iii or iv.

6. “Concerns”

Compared to Non-*AA* Alternatives

“Object pools and factories serve to reduce overhead caused by allocating memory; so why aren’t these other approaches as good (if not better) alternatives to allocators?”

Compared to Non-*AA* Alternatives

“Object pools and factories serve to reduce overhead caused by allocating memory; so why aren’t these other approaches as good (if not better) alternatives to allocators?”

- Memory allocation is reduced, not obviated, and only in certain cases.

Compared to Non-*AA* Alternatives

“Object pools and factories serve to reduce overhead caused by allocating memory; so why aren’t these other approaches as good (if not better) alternatives to allocators?”

- Memory allocation is reduced, not obviated, and only in certain cases.
- Do moving vans eliminate the need for furniture companies?

Compared to Non-*AA* Alternatives

Object pools are ***not*** replacements for allocators.

1. Object pools are not faster than allocators.
2. They are at different levels of abstraction:
   - Object pools minimize construction/destruction
   - Memory pools minimize allocation/deallocation
3. Object pools are created using memory pools
4. Object pools themselves should naturally be *AA*
   - That way they *too* can enjoy the *collateral benefits*!

6. “Concerns”

End of Section

Discussion?

6. “Concerns”

End of Section

Questions?

6. “Concerns”

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Conclusion

Allocator-Aware Software Infrastructure (*AA*SI):

- Custom memory allocation strategies' impact:
  - Performance
  - Instrumentation
  - Object placement **…**
- Historically, required bespoke data structures:
  - Long delivery time
  - Any collateral benefits cost extra
  - No reuse **…**

Conclusion

*AA*SI has real costs:

- "Fixed" engineering costs (for SI developers)
- Added operational costs
  - Documentation
  - Training
  - Developer-facing tools
  - Risk of misuse
- Resistance based on C++11-style allocators

Conclusion

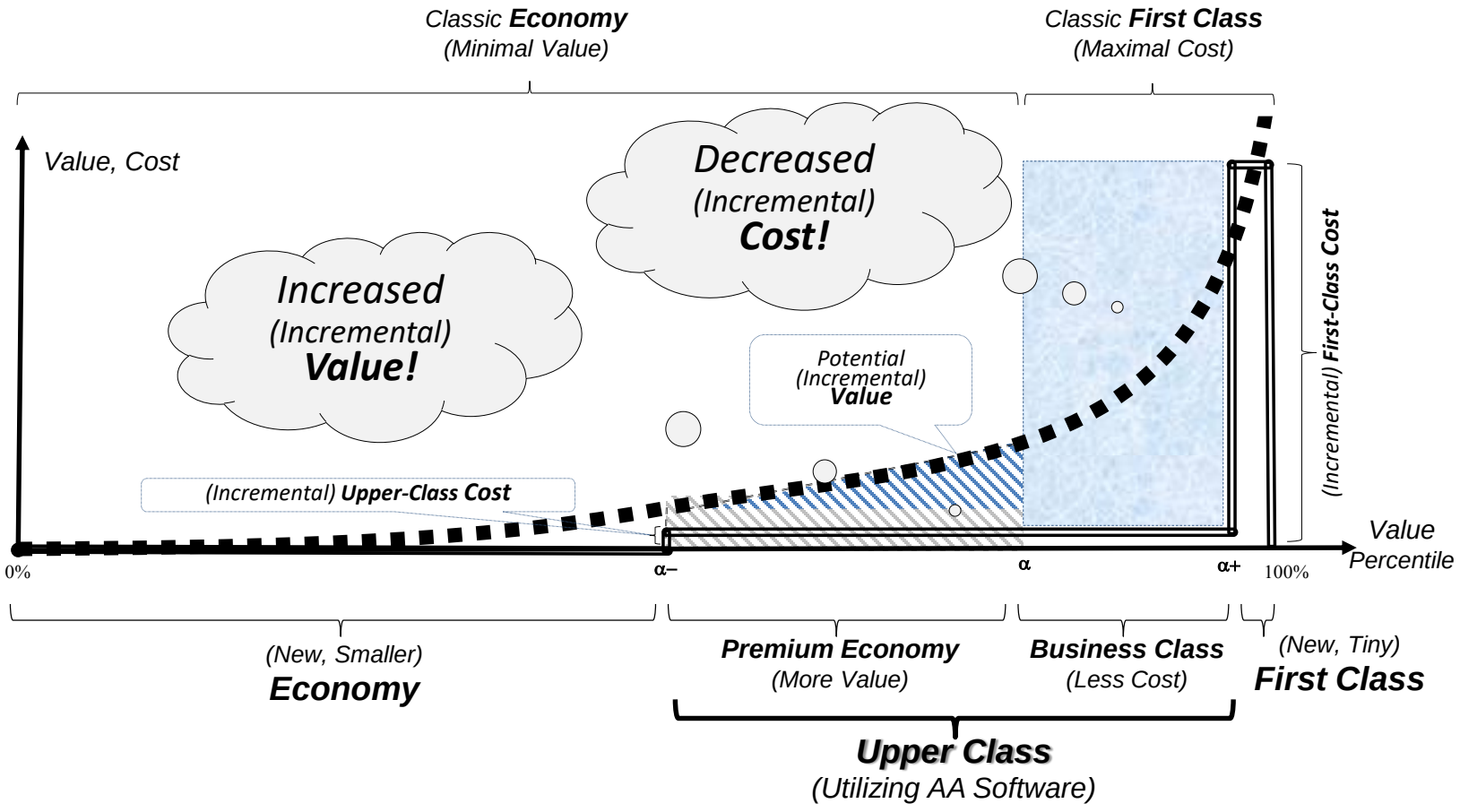
Investing in an *AA*SI is an economic decision:

- Provides nearly same runtime performance
- Lower incremental cost -> used more often
- Requires substantial up-front cost
- Comes with important collateral benefits
- C++11 experience -> “concerns” (F.U.D)

Do the benefits outweigh the costs?

Conclusion

Cost/Benefit of Utilizing Allocator-Aware (AA) Software



Conclusion

WAIT!!

Conclusion

WAIT!!

What if ***BB20V*** could eliminate ***<u>all</u>*** *fixed* costs ***entirely?***

Conclusion

WAIT!!

What if ***BB20V*** could eliminate ***all*** *fixed* costs ***entirely?***

Now what do you say?

Conclusion

Should we (e.g., Bloomberg) invest in *AA*SI?

➔ How can we afford not to?! ➔

- The user benefits outweigh the costs *now*!

Conclusion

Should we (e.g., Bloomberg) invest in *AA*SI?

➔ How can we afford not to?! ←

- The user benefits outweigh the costs *now*!

What about BB20V?

- Eliminates (SI-library) "fixed" costs ***entirely!***
  - Analogous to self-driving car technology

Conclusion

Should we (e.g., Bloomberg) invest in *AA*SI?

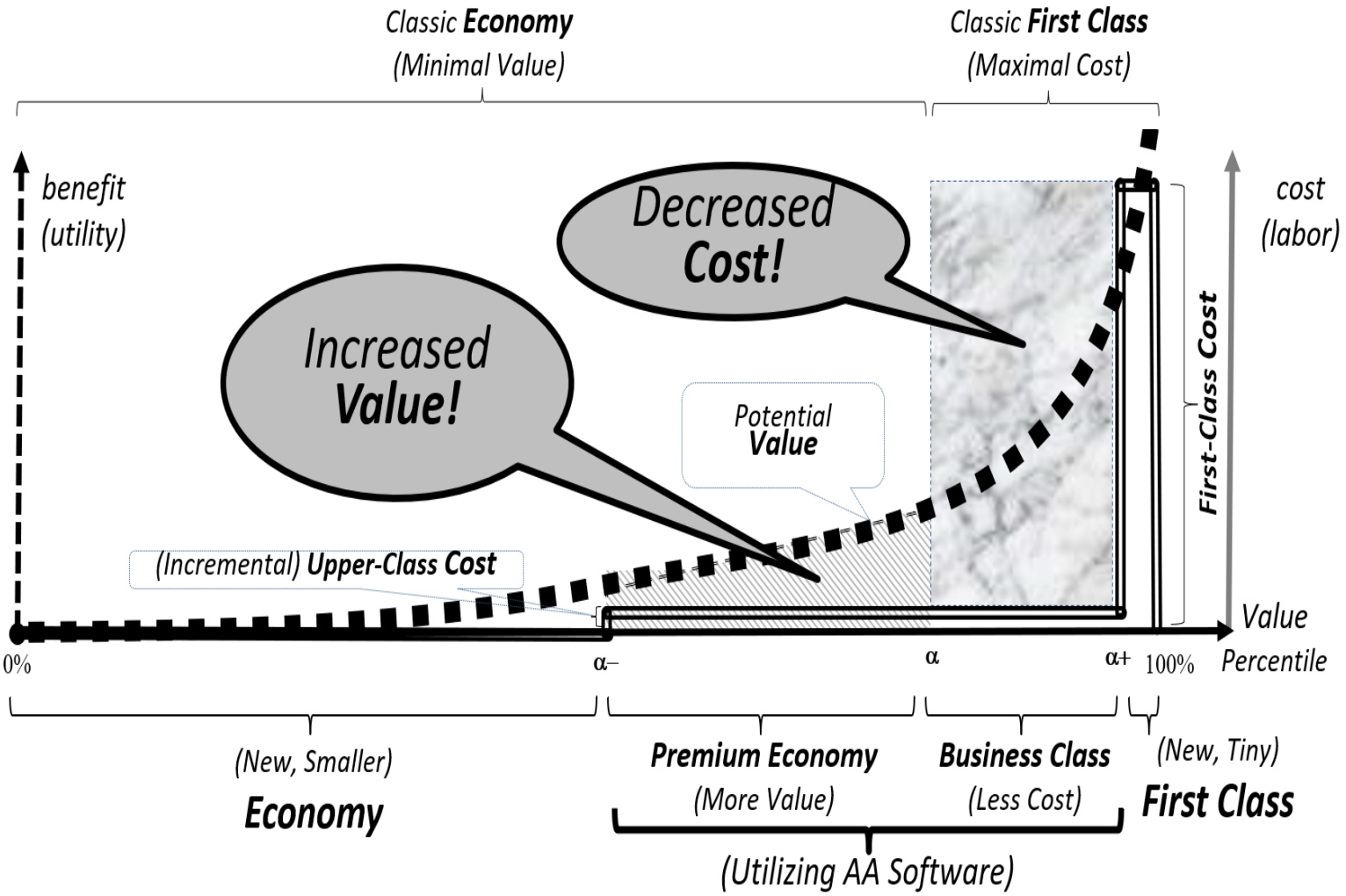
➔ How can we afford not to?! ←

- The user benefits outweigh the costs *now*!

What about BB20V?

- Eliminates (SI-library) "fixed" costs ***entirely!***
  - Analogous to self-driving car technology
- Reduces (client) "use" costs to ***bare minimum***
  - Akin to using virtual functions in C++ today

Conclusion


Classic Economy
(Minimal Value)
Classic First Class
(Maximal Cost)
benefit
(utility)
cost
(labor)
Decreased
Cost!
Increased
Value!
Potential
Value
First-Class Cost
(Incremental) Upper-Class Cost
Value
Percentile
0%
α–
α
α+
100%
(New, Smaller)
Economy
Premium Economy
(More Value)
Business Class
(Less Cost)
(New, Tiny)
First Class
(Utilizing AA Software)

Conclusion

The End